LEVEL II

12

NADC-79256-60

AD A101640

CH-53E EMERGENCY FLOTATION SYSTEM DESIGN STUDY

BY

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JULY 1981

CONTRACT N62269-80-C0210

DISTRIBUTION UNLIMITED

PREPARED FOR

NAVAL AIR DEVELOPMENT CENTER
WARMINSTER, PA 18974

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July 15,1981

SEL-5954

Commander Naval Air Development Center
Warminster, Pennsylvania 18974

Attention: Code 6054(HD)

Via Naval Plant Representative Office, Stratford, Connecticut

Subject: Submittal of Final Technical Report, CH-53E Emergency Flotation System Design Study

Reference: (a) Contract N62269-80-C-0210, Contract Data Requirements List DD Form 1423 Sequence Number A003

Enclosure: (1) Final Technical Report "CH-53E Emergency Flotation System Design Study", NADC-79256-60 (SER-13452)

(2) Annotated Preliminary Technical Report "CH-53E Emergency Flotation System Design Study" SER-13452

Enclosure (1) is submitted in accordance with Reference (a). Enclosure (1) incorporates the corrections and comments suggested in Enclosure (2).

Very truly yours,

UNITED TECHNOLOGIES CORPORATION

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KCH:sr

CC: NADC 8131 (3)
DDC (12)

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	NADC-79256-60
2. GOVT ACCESSION NO.	AD-A101 640
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle)	CH-53E Emergency Flotation System Design Study
5. TYPE OF REPORT & PERIOD COVERED	Final Report
6. PERFORMING ORG. REPORT NUMBER	SER-13452
7. AUTHOR(s)	Hansen, K. and Lawrence, T. H.
8. CONTRACT OR GRANT NUMBER(s)	N62269-80-C-0210
9. PERFORMING ORGANIZATION NAME AND ADDRESS	Sikorsky Aircraft Div. United Technologies Corp. N. Main St. Stratford, Conn. 06602
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	Airtask W11090000
11. CONTROLLING OFFICE NAME AND ADDRESS	Naval Air Development Center Warminster, PA 18974
12. REPORT DATE	6/10/81
13. NUMBER OF PAGES	99
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	
15. SECURITY CLASS (of this report)	Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

JUL 21 1981

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Capsize
Flotation/Stability System
H-53 Helicopter
CH-53 Helicopter

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Auxiliary flotation and stability systems were studied for use on CH-53E helicopters. Inflatable bags were found to offer the capability to evacuate a full complement of troops from a flooded cabin in sea state 5. Logistics, weight and performance penalties were estimated. A description of the 1/10 Froude scaled model concurrently built for wave tank testing is included.

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S/N 0102-LF-014-6601

323800

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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1.0 SUMMARY

A study has been conducted to design an auxiliary flotation/stability system for the CH-53E helicopter which will keep the aircraft upright and afloat (with the cabin flooded) long enough to allow the evacuation of a full complement of combat troops. Configurations were made to be compatible with the proposed MH-53E helicopter and MCM equipment as well. The study showed that inflatable flotation bags provided the best design solution. Three such systems were designed in detail, one each for sea states 2, 4, and 5. Increasing system capability from sea state 2 to 5 results in only a slight increase in cost. The final systems should have acceptable reliability and maintainability characteristics, minimal impact on performance, and only cause a small weight penalty.

In addition, a 1/10 Froude scaled model of the CH-53E and the auxiliary flotation systems has been designed and constructed. This model will be provided to the U.S. Navy for hydrodynamic testing.

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FORWARD

This report presents results of a design study of an auxiliary flotation/stability system for the CH-53E helicopter. The program technical direction was provided Naval Air Development Center, Warminster, Pennsylvania, under the direction of Harold Dewhirst. Funds for this effort were provided by the Naval Air Systems Command AIR-340B Office.

The following Sikorsky employees made technical contributions to this report:

Mr. Edmond Kiely	Model Design
Mr. Thomas Lawton	Model Design
Mr. Carmen Perruzzi	Flotation System Design
Mr. Graham Willoughby	Flotation System Design

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2.0 INTRODUCTION

2.1 Background

The Sikorsky CH-53E helicopter will provide the U.S. Navy and Marine Corps with a highly capable and versatile platform for performing the following missions:

. Long Range Deployment
. Vertical Replenishment
. Search and Rescue
. Troop and Equipment Deployment
. Equipment and Aircraft Recovery
. Amphibious Operations Support
. Ship-to-Shore Cargo Transport
. Vertical-On-Board-Delivery
. Airborne Mine Countermeasures

In the performance of these missions, the aircraft spends a large portion of its time operating over water and, therefore, may be subject to emergency water landings.

The CH-53E was designed to be ditchable and stable in water conditions up to Sea State 2. This capability was based on the assumption that the cabin remained watertight and provided both buoyancy and stability. In addition, there are sealed volumes under the cabin and cockpit ("tubs") and fuel cells in the sponsons which also provide buoyancy and stability.

Since some of the above missions require operation at low altitudes with the personnel door open and/or the cargo ramp down, it may be impossible to secure the aircraft prior to an emergency water landing. In addition, the single-point suspension hatch in the center of the cabin may be open, or the cockpit glazing may be shattered by water impact upon landing. Any of these eventualities can lead to the cabin becoming flooded. In this event, the remaining sealed volumes cannot provide sufficient buoyancy and the aircraft will sink.

The U.S. Navy has requested that Sikorsky Aircraft conduct a design study to find ways for improving CH-53E sea keeping capabilities following an emergency water landing. The specific guidelines were:

1. Define systems for maintaining the CH-53E upright and afloat long enough for the successful evacuation of a full troop complement.

2. Systems for performing this task in sea states 2, 4, and 5 with the cabin flooded should be evaluated.

3. Systems are only required to keep aircraft afloat long enough for successful personnel evacuation. However, systems which would keep the aircraft afloat long enough to allow recovery are desirable.

4. Systems should be practical for the aircraft's operational environment and have minimal impact on aircraft performance.

5. Systems should be compatible with the proposed MH-53E helicopter.

6. Sikorsky shall design and construct a scale model of the CH-53E and proposed flotation systems for use in towing tank tests. The U. S. Navy will conduct the tests.

The requested study has been completed and is documented in this report.

2.2 Study Outline

The study was conducted in five phases, discussed below:

Phase I - Flotation System Requirements (Section 3.0)

This phase involved a review of CH-53A/D water accidents, a determination of basic CH-53E hydrodynamic characteristics with and without cabin flooding, and a delineation of the additional buoyancy and stability required to meet study guidelines.

Phase II - Conceptual Design Studies (Section 4.0)

A wide array of systems for improving buoyancy and stability were investigated. This resulted in a decision to use conventional inflatable auxiliary flotation bags to provide additional buoyancy and stability.

Phase III - Preliminary Design Study (Section 5.0)

This phase was conducted to define the basic characteristics of systems using flotation bags which would meet the study guidelines.

Phase IV - Trade-Off Study (Section 6.0)

In this phase, the preliminary designs were evaluated with respect to reliability and maintainability, weight, drag, and cost. Three systems were selected as best, one for each sea state.

Phase V - Detailed Design (Section 7.0)

The three selected systems from Phase IV were designed in more detail and system characteristics more precisely defined.

In addition to the analytical studies above, a 1/10 Froude-scaled model of the CH-53E was designed and constructed for use in Navy towing tank tests. (Section 8.0)

3.0 FLOTATION SYSTEM REQUIREMENTS

The flotation system requirements were determined in the following way. First, CH-53A/D water accidents were reviewed since the CH-53E is a derivative of these earlier aircraft and has the same fuselage but larger sponsons. These data were used to derive design guide lines for flotation/stability systems. Next, the inherent buoyancy and stability characteristics of the baseline CH-53E were determined, for cases with and without cabin flooding. These hydrodynamic characteristics were then used to determine the additional requirements for sea states 2, 4, and 5. Finally, the decay in main rotor RPM and control power following an autorotative landing was analyzed. These data were used to determine the time available for system actuation.

3.1 Review of CH-53 Accidents On Water

The accident data compiled in this report and presented in Appendix A was obtained from the Naval Safety Center, Norfolk, Va. This appendix contains all the Navy/Marine CH-53 accidents occurring on the water in the time period May 1968 to June 1979.

As a result of the findings of this study of CH-53 Navy/Marine helicopter accidents, the following design guide lines were established relative to the design criteria for stability and flotation of CH-53E.

DESIGN GUIDE LINES

A helicopter flotation/stability system design shall accomplish the following:

1. Accommodate the full range of aircraft weight and center-of-gravity locations.

2. Accommodate the full range of anticipated aircraft configurations. Closures, such as doors, windows, hatches, etc. that may be opened in flight shall not be considered closed in emergency or accident situations.

3. Keep the aircraft upright in sea state 3 (3 to 5 foot waves) with winds to 30 knots, and keep the aircraft afloat for a time sufficient for the evacuation of a full complement of crew and passengers in these conditions.

3.2 CH-53E Basic Hydrodynamic Characteristics

Hydrodynamic characteristics of the CH-53E were determined with the cabin both sealed and flooded. The baseline aircraft modeled was a CH-53E in troop transport configuration with external auxiliary fuel tanks jettisoned and a full load of internal fuel. This corresponds to a gross weight of 24,444 kg (53,889 lb.) and a center-of-gravity location of fuselage station (FS) 9.06m. (356.7 in.), waterline (WL) 4.19m. (165.1 in.) and buttline (BL) 0.048m. (1.9 in.). All buoyancy and stability calculations assume fresh water density of 1000 Kg/m^3 (1.94 $slug/ft^3$). Buoyancy and righting moment were calculated with the aircraft level in the water and submerged to various depths. The nose landing gear and main landing gear wells were assumed to be flooded.

Buoyancy

The aircraft has four major sources of buoyancy:

1. A sealed tub under the cabin floor
2. A sealed tub under the cockpit floor
3. The sponsons
4. The cabin itself

The buoyancy of each of these volumes was calculated for the aircraft level in the water and submerged to depths corresponding to WL's 2.46m. (97 in.), 2.72m. (107 in.), 2.97m. (117 in.), 3.26 m. (127 in.), and 3.48 m. (137 in.) as shown in Figure 1.

Two configurations were evaluated. First, the cabin was assumed to be watertight as intended in the original design. This large cabin volume contributes significantly to overall buoyancy. In the second configuration, the cabin was assumed to be flooded. This situation could arise if the aircraft entered the water with the cargo ramp down, personnel door open or the single-point access hatch uncovered, for example. <u>It should be noted that numerous openings exist between the inside of the cabin and the tub under the cockpit; therefore, the nose tub was assumed to be flooded any time the cabin was flooded.</u>

The external auxiliary fuel tanks were not included in the buoyancy calculation since they are normally jettisoned prior to an emergency landing. In addition, the tanks and their supporting pylons are not designed for water impact loads and would probably be damaged during an emergency water landing.

The results of the buoyancy calculations are presented in Figure 2 and tabulated in Tables I and II. Note that adequate buoyancy will exist if the cabin is watertight and the aircraft will float at WL 2.92m. (115 in.). If the cabin is flooded, the only sealed volumes available are the cabin tub and the sponsons. These provide a total buoyancy of 13,271 kg (29,258 lb.), which is inadequate to maintain flotation and the helicopter will sink.

Therefore, a minimum of 11,172 kg (24,631 lb.) of buoyancy must be provided by the auxiliary flotation system to maintain the aircraft afloat.

Hydrodynamic Stability

The roll direction is critical for the CH-53 due to the location of displaced volumes at shorter moment arms than those which are available in pitch. For that reason, hydrodynamic stability is assessed by investigating the aircraft's roll characteristics.

A semi-emperical method of analysis developed by Sikorsky Aircraft was used to evaluate the hydrodynamic roll stability of the CH-53E and to define the requirements for the auxiliary flotation system. This method of analysis is based on hydrodynamic model test data of the CH-53A aircraft. This analysis requires knowing the righting moment, the lateral imbalance, and hydrostatic wind capability of the aircraft. The details of the analysis are discussed below.

Basic Stability Characteristics

The CH-53E righting moment was determined as a function of roll angle. The aircraft was assumed to be level in the water at the same depth increments used in the buoyancy calculations. At each depth, the aircraft was rolled to angles of 3, 6, 9, 12, 15, and 18 degrees, as shown for a typical case in Figure 3. At each depth and roll angle, the gross righting moment was determined by calculating the rolling moments due to the various submerged volumes and to the aircraft's mass at its center-of-gravity as indicated in Figure 4. Two configurations were investigated, one with the cabin sealed, the other with the cabin and nose tub flooded. The results are shown in Figure 5 and 6, respectively.

Without flooding, the CH-53E is inherently stable when submerged to waterline 2.72 m. (107 in.) and 2.97 m. (117 in.). The instability at waterline 2.46 m. (97 in.) is due to the large weight moment since the center-of-gravity is so far above the roll axis. The instability at waterlines 3.26 m. (127 in.) and 3.48 m. (137 in.), is due to the complete submergence of the downside sponson. With the sponson completely submerged, increases in righting moment are not produced as roll angle increases. The only stabilizing forces available come from the cabin volume and the effect of rolling the upside sponson out of the water.

With the cabin flooded, Figure 6, the aircraft is unstable for all depths investigated.

The curves of Figure 5 and 6 represent the gross righting moment available. Two other effects are normally present. One is the lateral center-of-gravity offset of .048 m. (1.9 in.) inherent in the aircraft design and is due to the asymmetry of the tail rotor, engine configuration, and auxiliary equipment. This lateral offset reduces the gross righting moment by 11,568 N-m (8532 ftlb.). The second effect normally present with an articulated rotor is the lateral offset of the rotor center-of-gravity due to the blade lead-lag degree-of-freedom. The CH-53E lag dampers are preloaded to hold the blades against their lead stops when the rotor is stopped. With all the blades against their lead stops, the lateral imbalance due to lead-lag is zero. Thus, the net righting moment is equal to the gross righting moment less the moment due to the lateral center-of-gravity offset. This moment represents the true capability of the aircraft.

Analytical Methodology

The method of analysis used to evaluate the sea state capability of the CH-53E is shown in Figure 7, which is a plot of wave height versus wind velocity. The curve denoted "CH-53A capability" is reproduced from the CH-53A hydrodynamic report SER-50296, Reference 1, and shows combinations of wave height and wind velocity that the aircraft can sustain without capsizing. The shape of the CH-53A curve was developed from test results obtained from a 1/20th scale model test performed at the Davidson Laboratory of Stevens Institute of Technology. In this test, an artificial roll moment was placed on the model and wave height was varied until a capsize occurred. This process was repeated until the roll moment was just equal to the maximum righting moment available. (i.e., the point at which the aircraft would capsize without any waves.)

Each artificial roll moment could be related to a side wind velocity which would produce that moment. The maximum righting moment the aircraft can generate can be equated to a maximum side wind capability. This is defined as the hydrostatic wind capability.

For the CH-53A, Figure 7 shows that the aircraft could withstand a wave height of 2.2 meters without any wind or a side wind of 20 meters/second without any waves, so its hydrostatic wind capability is 20 meters/second. To relate this capability to real sea state conditions where wind and waves act together, a standard sea state curve is also shown on Figure 7. Its intersection with the CH-53A capability line defines the CH-53A's sea keeping qualities. In this case, the intersection corresponds to a wave height of 1.65 meters (5.4 feet) and a wind velocity of 9 meters/second (1.75 knots), representing a lower sea state 4 capability.

In order to evaluate the effects of different configurations or flotation systems, the maximum available righting moment is determined. This is then equated to a hydrostatic wind capability derived from conventional aerodynamic calculations. The resulting wind velocity is then plotted on a graph like Figure 7. A line parallel to the original curve is then drawn on the graph. Its intersection with the standard sea state curve then defines the sea state capability of that configuration.

Determination of Required Capabilities

The hydrostatic wind capability is defined as the maximum side wind the aircraft can withstand without capsizing in calm water. The hydrostatic wind capability is determined by calculating the wind moment that is equal to the maximum net righting moment, using the following equation:

$$M_W = 1/2 \rho_A \, C_D \, S_e \, \ell \, (V_W)^2$$

Where:

M_w = wind moment, N-m (ft-lbs)

ρ_A = air density, 1.225 Kg/m^3 (.002378 $Slug/ft^3$)

C_D = drag coefficient

S_e = equivalent broadside area above waterline, m^2 (ft^2)

ℓ = moment arm from fuselage center-of-pressure to reference waterline m (ft)

V_w = wind velocity, m/sec (ft/sec)

Normally, the term $C_{D}S_{e}\ell$ is lumped together as a rolling moment parameter, L/q, m^3 (ft^3). When multiplied by the dynamic pressure, $1/2\rho_A (V_W)^2$, it yields the wind moment. The values of L/q for the CH-53E at the various depths investigated are presented in Table III.

The total net righting moment (fuselage plus auxiliary flotation devices) required for sea states 2, 3, 4, and 5 were determined using Figure 8. A line was drawn from the sea state scale to the standard sea state line, and from this point, a line parallel to the CH-53A capability line was drawn until it intersected the wind velocity axis. This intersection point is the wind velocity the CH-53E must be designed to withstand to achieve a given level of sea state stability. The corresponding wind moment, M_w, and wind velocity are given in Table IV for sea states two, three, four, and five. For example, the aircraft must be able to withstand a side wind of 19.6 m/sec (38.2 knots) if it is to have a Sea State Three capability. If the aircraft is submerged to WL 2.72 m. (117 in.), the righting moment that must be provided is:

$$M_{REQD} = 1/2\,\rho_A\,(19.6)^2\ (L/q)_{WL\ 2.72}$$

$$= 1/2\,\rho_A\,(19.6)^2\ (123.38)$$

$$M_{REQD} = 29{,}031,\ \text{N-M}\ (21{,}412\ \text{ft-lbs})$$

Thus, the basic aircraft, plus the auxiliary flotation system, must together generate a maximum righting moment of 29,031 N-m if the aircraft is to be stable in Sea State Three when floating at WL 2.72 m. (117 in.).

The CH-53E stability requirements are summarized in Figures 9 to 13. These figures show the net righting moment versus roll angle for each depth increment studied along with the maximum righting moment required for various sea states. The most stable case shown is with the cabin unflooded and the aircraft at WL 2.72 m. (117 in.). For this condition the aircraft is stable to Sea State Two. To increase its capability to Sea State Five, an additional righting moment of 99,000 N-m (73018 ft-lb) is required without cabin flooding and 126,400 N-m (93228 ft-lb) with the cabin flooded and rolled to 12 degrees.

The peak righting moment without cabin flooding for each WL is presented in Figure 14. As can be seen when the CH-53E is submerged to WL 2.92 m. (115 in.) which provides neutral buoyancy at a Gross Weight of 2444 Kg (53889 lb.), the aircraft has an inherent Sea State Two capability. Thus, even without cabin flooding an additional righting moment is required to obtain Sea State Three and above capability.

3.3 Rotor Decay Characteristics

One important design feature of any flotation/stability system is whether or not it is deployed before the water landing. If deployed before, it must withstand water impact loads which can be very severe. If deployed after the landing, the question arises as to how long the deployment can or should be delayed.

The basic senario envisioned in this study involves an emergency, autorotative landing on the water. To keep the system weight reasonable, it was decided that any system considered would be deployed after the landing. In addition, an emergency landing from low altitude may not allow time for deployment of the flotation/ stability system.

After an autorotative landing, the pilot can still control the aircraft with cyclic inputs as long as the rotor RPM is reasonably high; say 70% or higher. The decay of rotor RPM following an autorotative flare was determined from CH-53E flight test data.

The decay of rotor speed is shown in Figure 15 with the main rotor collective at its low position, 10%, following a full engine cut. As can be seen, it will take approximately ten seconds for the rotor speed to decay from 100% to 71% which is the rotor speed where the rotor control power will be reduced in half. If the rotor speed is at 90%, which is the approximate rotor speed following an autorotative flare, it will take approximately six seconds for the rotor to slow to 71%. Thus, the deployment of the flotation/stability system should take less than six seconds.

4.0 CONCEPTUAL DESIGNS

The traditional method for adding buoyancy and hydrodynamic stability to a helicopter is use of auxiliary inflatable flotation bags. This technique has been applied very successfully by both Sikorsky (S-58, S-61, S-62, S-76, SH-60B) and other helicopter manufacturers. During the initial phases of this study, it became clear that the inflatable floats required to support and stabilize the CH-53E in sea state 5 would be very large. Therefore, while the detailed hydrodynamic characteristics of Section 3.0 were being calculated, a conceptual design study was undertaken to determine if there were any other practical approaches for providing emergency flotation.

Concepts Investigated

In addition to preliminary layout and sizing of auxiliary flotation bags, a number of other concepts were investigated. These included:

1) Extendable Weight - This system would have a weight on the end of a folding or telescoping boom. The boom would be lowered/extended below the aircraft to lower the center-of-gravity and provide a stabilizing moment and damping.

2) Boom Floats - This concept envisioned the use of small, inflatable floats on the ends of folding booms. In use, the booms would fold out from the fuselage and the floats would inflate to create stabilizing outriggers. Some attention was paid to having the inflation of the floats act to deploy the boom also, so that a separate extension mechanism would not be required.

3) Dagger Boards - Another scheme investigated was the use of dagger boards on the sponsons to provide stability and damping.

4) Component Ejection - This system would employ pyrotechnic charges to sever the main rotor blades and tail pylon from the aircraft. Technology verified during the design of the Rotor Systems Research Aircraft (RSRA) would be used to insure adequate reliability. Such a system would significantly reduce the weight of the aircraft, reduce the side area exposed to the wind, and lower the center-of-gravity.

In addition to the schemes outlined above, various combinations of these schemes, with and without inflatable floats, were also evaluated.

4.2 Results

As the buoyancy and hydrodynamic stability data in Section 3.0 was accumulated, it became obvious that any emergency flotation system would have to, first of all, provide a significant amount of buoyancy, on the order of 10,000 kg (22,000 lb) or 10 cubic meters (350 cubic feet) of displaced volume. This is obviously best done with inflatable floats. Further calculations showed that once floats of sufficient size to provide the required buoyancy were utilized on the aircraft, the hydrodynamic stability requirements could be achieved by making relatively small increments in the float sizes.

In addition, the schemes proposed above all had some common disadvantages. These were:

1) They all required some form of mechanization. This would have increased maintenance relative to inflatable floats which are essentially passive. In addition, a very real question of reliability arises with folding/telescoping joints and actuators that sit quiescently for long times in a salt water environment.

2) All of the conceptual systems above would probably involve a significant weight penalty compared to inflatable floats.

3) Inflatable floats are a technology with well established design criteria, known material characteristics, and proven operational reliability. The other systems were not, and in some cases might carry significant developmental risk.

Therefore, at the end of the conceptual design study, it was clear that conventional inflatable flotation bags offered the best solution for CH-53E emergency flotation.

5.0 PRELIMINARY DESIGN STUDY

As indicated in Section 4.0, the result of the conceptual design study was a decision to utilize conventional inflatable flotation bags to provide the required buoyancy and stability for the CH-53E. Eight configurations were laid out initially, but two proved to be unacceptable. Preliminary design of the remaining six systems was completed. The results of this effort are discussed below.

5.1 Design Philosophy

The following design philosophy was adopted for all of the auxiliary flotation systems:

1) Each system would provide adequate buoyancy and stability for the given sea state conditions with the cabin and nose tub flooded.

2) Each system would provide a three degree nose-up trim pitch attitude. This increases the clearance between the rotor plane and the water since the aircraft has a five degree forward shaft tilt.

3) Each system would provide the required stability and neutral buoyancy when the aircraft was submerged to WL 2.97 m. (117 in.) at FS 8.64 m. (340 in.) (except for System Three which had neutral buoyancy at WL 2.90 m. (114 in.) at FS 8.64 m.). This geometry will submerge the person in the most aft troop seat up to his or her waist, thus allowing for easy egress either forward or aft.

4) Multicompartment floats with check valves would be used to increase system safety. In the event one compartment was damaged, the other compartment(s) would not deflate. Systems would be designed to maintain buoyancy but have reduced stability for any single compartment failure.

5) Each system would have an inflation time of four seconds. This is practical if helium is used, but would require very large lines if nitrogen is used as the inflating medium.

6) Each system was designed to be compatible with the proposed MH-53E helicopter featuring "enlarged sponsons". Floats, float stowage, and inflation systems were all located so as not to interfere with MCM equipment.

5.2 Calculation of Righting Moment

The righting moment characteristic of each system was calculated assuming the aircraft rolled about its trim waterline. The effect of the aircraft settling in the water to maintain neutral buoyancy was also explicitly modeled. Note that as the aircraft rolls, the buoyancy from the tub and sponson decreases and the floats must settle further into the water to maintain neutral buoyancy. This settling reduces their righting moment capability. In calculating the righting moment of each system a fresh water density of 1000 kg/m^3 (1.94 $slugs/ft^3$) was used and it was assumed the floats were only 75% effective to account for the deformation of the float as it is submerged.

5.3 Background

The auxiliary flotation systems were designed to meet the buoyancy and stability requirements outlined in Section 3.0. Three configurations were designed for sea state 5, two for sea state 4 and one for sea state 2. These are shown in Figures 16 to 21.

In addition to these six float configurations, two other concepts were evaluated and discarded. The first configuration consisted of two large floats, one on each sponson. To obtain the desired stability and buoyancy the floats had to be longer than the sponsons. The structure outboard of the wheel wells is inadequate to support these floats and would require a great deal of structural modification. Thus, there was inadequate structure available to attach the floats along their entire length. Due to this lack of support, the ends of the floats would deflect up when submerged and they would become ineffective.

The other configuration utilized three floats. In this case the nose float was wrapped around the cockpit of the aircraft. The other two floats were located aft of the sponson in a manner similar to those shown in configuration one, Figure 16. This configuration was rejected due to lack of load bearing structure on the cockpit. If the plexiglass shattered, the bag could become torn and buoyancy would be lost. Therefore, both of these designs were eliminated from further study.

5.4 System Description

General

Each float is inflated with helium from its own separate fiber glass bottle and is designed to operate at pressures between 8.62 kPa (1.25 PSIG) and 24.1 kPa (3.5 PSIG). Helium is used as the inflating medium to allow for a four second inflation time (derived from the time of six seconds for rotor RPM decay from 90 to 70 percent). The floats used in all systems except six have multi-compartments. An inflation line runs from each bottle to a manifold. Lines run from the manifold to each compartment in the float. Check valves will be located either in the float or the manifold for each compartment. In the event a compartment becomes damaged the check valves will prevent the other compartments from becoming deflated. A nozzle in the check valve is designed to choke the flow during inflation, so that if a compartment is damaged prior to inflation, all the gas will not escape out through the damaged compartment, but will be available to inflate the other compartments. Inflation bottles, plumbing and floats for all systems are designed to be compatible with the planned MCM equipment and enlarged sponsons of the MH-53E helicopter.

The preliminary design results are summarized in Tables V and VI. Table V gives the float characteristics for each system, including number of floats, float size, and number of compartments. The system characteristics are given in Table VI, including system weight, buoyancy, inflation bottle number and size, and line sizes.

The specific characteristics of each system are discussed below.

System One

System One is a four float configuration designed to provide sea state 5 stability. The general arrangement is shown in Figure 16 and the righting moment characteristics in Figure 22.

The four floats are disposed two forward and two aft, one on each side of the fuselage. All floats are cylindrical with a diameter of 1.83 m. (6.0 ft). The forward floats are 2.13 m (7.0 ft.) long while the aft ones are slightly longer at 2.65 m (8.7 ft). Each of the flotation bags is divided into three separate compartments via vertical diaphragms.

Assuming the float volume and buoyancy to be 75 percent of the nominal value (in order to account for distortion), system one provides an additional buoyancy of 18,867 kg (41,595 lbs.) and gives the aircraft a total righting moment capability of 70,900 N-m (52,293 ft-lbs) at a twelve degree roll angle. This system brings the total available aircraft buoyancy (cabin flooded) up to 32,395 Kg (71,419 lbs) and provides stability to Sea State 5.

The aircraft will float with a three degree nose-up attitude and with a one degree roll to port. This roll is due to the lateral center-of-gravity offset. From a failure standpoint, the aft port float is the most critical. With a failure of one compartment in this float, the total available buoyancy (aircraft plus floats) is reduced slightly to 29,254 kg (64,493 lbs.), but the righting moment capability is reduced to around 10,000 N-m (7,376 ft-lbs), giving a limiting sea state of 2. This failure would also increase the port roll from one degree to five degrees.

The nose floats are stored within the electronics compartment door. This requires a new fiber glass door with a bump to accommodate the floats and modifications to the hinges and latches so that they can react the float loads.

The aft floats are stowed internally in fuselage compartments between FS 13.3 m. (522 in.) and 13.8 m. (545 in.). The fuselage would require structural modifications in the form of cut-outs and doublers in the affected areas, while the floats would be contained in fiber glass boxes.

System Two

System Two is a four float configuration, also designed to provide sea state 5 stability. In this case, two floats are mounted amidship, one on each sponson, and two are mounted aft on the tail boom. The general layout is shown in Figure 17 and the righting moment capability in Figure 23.

All floats are cylindrical. The sponson floats are 1.54 m. (5.05 ft) in diameter and 5.33 m. (17.5 ft) long with five compartments each. The aft floats are 1.19 m. (3.9 ft) in diameter and 1.62 m. (5.3 ft) long and contain two compartments each.

System Two provides an additional buoyancy of 17,589 Kg (38,777 lbs.), bringng the total aircraft capability (cabin flooded) up to 31,117 Kg (68,601 lbs.). The righting moment capability of the aircraft with this system is 69,100 N-m (50,966 ft-lbs) at a roll angle of 11 degrees, giving a sea state 5 capability.

With the critical sponson compartment damaged, the buoyant capability of the aircraft is reduced slightly to 29,254 kg (64,494 lbs.) while the maximum righting moment available is reduced to less than 1000 N-m (738 ft-lbs.).

The sponson floats are housed in soft covers on the outside of each sponson in a manner similar to the SH-3A/D/H packaging. Two external doublers will be added to the bottom of the sponson to react float loads. In addition, the fairing on the leading edge of the sponson would be modified to accommodate the inflation bottles.

The aft floats are attached to the tail cone and protected with breakaway fiber glass covers. External doublers would be added to react the float loads. The inflation bottles for the aft floats would also be located in the tail cone and appropriate access panels would be provided.

System Three

System Three is a six float configuration, also designed to provide stability in sea state 5. The general arrangement is shown in Figure 18 and the righting moment characteristics in Figure 24. There are four fuselage floats, two forward and two aft, mounted in the same manner as the floats in System One. There are also two sponson floats, one on the outboard portion of each sponson as in System Two. Again, all floats are cylindrical with the forward and aft floats having a diameter of 1.71 m. (5.6 ft) and lengths of 2.19 m. (7.2 ft) and 2.71 m. (8.9 ft), respectively. The sponson floats are 1.07 m. (3.5 ft) in diameter and 2.68 m. (8.8 ft) long. The fuselage floats have four compartments each, while the sponsons floats only have two each.

System Three floats have a total buoyancy of 20,453 kg (45,090 lbs.), bringing to total aircraft capability (cabin flooded) up to 33,980 kg (74,914 lb.). The addition of these six bags results in a maximum righting moment of 103,500 N-m (76,338 ft-lbs) being generated at a roll angle of 12½ degrees. This gives the system a substantial sea state 5 capability.

With the critical sponson compartment failed, buoyancy is reduced to 32,824 kg (72,365 lbs.) and the maximum righting moment available is 78,700 N-m (58,046 ft-lbs.), retaining the sea state 5 capability.

Attachment, stowage, and structural modifications required for the fore and aft floats are the same as those for System One. The sponson float stowage and structural modification requirements are the same as those for the sponson floats of System Two.

System Four

System Four is a four float configuration designed for sea state 4. It is esentially identical to System One except that the flotation bags and their inflation bottles have been reduced in size to reflect the lower requirements of Sea State 4. Bag attachment, stowage, and required structural modifications are essentially the same as those of System One. Figure 19 shows the general arrangement of this configuration while its righting moment curve is presented in Figure 25.

The floats all have a diameter of 1.71 m. (5.6 ft). The forward bags are 2.19 m. (7.2 ft) long, the aft 2.71 m. (8.9 ft.). All bags are divided into four compartments. Total bag buoyancy is 16,854 kg (37,157 lbs.), creating a total aircraft capability of 30,380 kg (66,977 lbs.). The system can generate a maximum righting moment of 37,500 N-m (27,659 ft-lbs.) when rolled nine degrees.

With a compartment in the critical aft port float deflated, the buoyancy is reduced to 30,123 kg (66,410 lbs.) and the righting moment capability is less than 2,000 N-m (1475 ft-lbs.), yielding only sea state 1 stability.

System Five

System Five is a four float configuration for Sea State 4 and is essentially a duplicate of System Two except that the inflatable bags and their inflation bottles have been reduced in size to reflect the lower requirements. Bag attachment, stowage, and required structural modifications are essentially the same as System Two. The layout is shown in Figure 20 and the righting moment curve in Figure 26.

The sponson floats are 1.49 m. (4.9 ft) in diameter and 5.18 m. (17.0 ft.) long. They are divided into seven compartments each rather than five as in System Two. This increase was necessary to provide positive buoyancy and stability with one sponson compartment flooded. The tail bags are 1.19 m. (3.9 ft.) in diameter and 1.62 m. (5.3 ft.) long, with two compartments each. Total buoyancy, aircraft plus bags (cabin flooded) is 29,845 kg (65,797 lbs.), of which the floats contribute 16,316 kg (35,971 lbs.). The aircraft generates its maximum righting moment of 45,000 N-m (33,190 ft-lbs) at a roll angle of ten degrees.

If the critical port sponson compartment fails, buoyancy is reduced to 28,710 kg (63,294 lbs.) and righting moment capability is reduced to around 4500 N-m (3319 ft-lbs). This gives stability only for sea state 1 conditions.

System Six

System Six is essentially a duplicate of Systems One and Four except that the floats and inflation bottles were sized for sea state 2 capability. Bag attachment, stowage, and required structural modifications are nominally the same as those for System One. A general arrangement drawing is provided as Figure 21, while the righting moment characteristics are plotted in Figure 27. Note that the maximum righting moment of 21,000 N-m (15,488 ft-lbs) occurs at eight degrees, and would nominally provide a sea state 3 capability. However, experience and tests indicate that the roll angles are generally higher than this; so, the righting moment at 12 degrees of roll (11,000 N-m (8113 ft-lbs)) was used to establish a sea state 2 capability.

The fore and aft floats are 1.74 m. (5.7 ft.) in diameter and have lengths of 2.01 m. (6.6 ft.) and 2.41 m. (7.9 ft.), respectively. Each float has only one compartment. If they had been designed to provide positive stability with one compartment failed, this would have required either a large number of compartments or floats large enough to have a sea state capability greater than 2 with all compartments inflated.

System Six can generate a buoyant force of 15,726 kg (34,670 lbs.) and increases the total available buoyancy to 29,254 kg (64,494 lb.), cabin flooded. With one aft float deflated, total system buoyancy is reduced to 24,976 kg (55,062 lbs). This is sufficient to float the aircraft modeled in this study, which has a gross weight of 24,444 kg (53,889 lbs.). However, with the aft float deflated, the aircraft is unstable and will roll over.

6.0 DESIGN TRADE-OFF STUDY

The design trade-off study was performed to select one configuration for the upper and mid sea states from those developed in the preliminary design phase. Sikorsky's MINICOMP Comparative Life Cycle Cost Model was used to perform this trade-off study. System reliability, maintainability, weight, drag and cost were used as the trade-off variables. The results are discussed below. Note that System Six was the only system designed for sea state 2, so no trade-off study was required. For completeness, however, the attributes of that system have been provided along with those of the other five candidates.

6.1 System Reliability and Maintainability

The following Reliability and Maintainability (R&M) attributes were evaluated for the trade-off study of the six flotation systems:

1. Failure Rate
2. Unscheduled maintenance manhours
3. Scheduled inspection time
4. Deployment Reliability

    Float deployment failure

    Rollover incidence

    Sinking incidence

The results of the analysis are presented in Table VII. From an R&M standpoint, the configurations employing four fuselage floats (Systems One, Four and Six) were preferred.

Failure rate, unscheduled maintenance manhours and scheduled inspection time were extrapolated from predicted values for the SH-60B emergency flotation system, based primarily on relative size and complexity factors. The following assumptions were made:

1. The arming and firing circuits have levels of reliability and redundancy equivalent to the SH-60B and are identical for all six system concepts.
2. The gas bottles, squibs and associated circuitry are independent in each system and of equal reliability.

3. Installation of and accessibility to system components would be generally equivalent to that of the SH-60B.

The R&M attributes for each system are discussed in detail below.

6.2 Reliability and Maintainability Attributes

Systems One, Four, and Six

It is estimated that systems one, four and six will have R&M characteristics slightly better than the other four float configurations (systems two and five) and substantially better than the six float configuration (system three). Although systems one, four, and six have a higher probability of a rollover incident in the event of a system malfunction, they have sufficient buoyancy with any one float deflated to keep the aircraft afloat versus systems two and five which will allow the aircraft to sink (cabin flooded) if one of the sponson floats fails to deploy.

Systems Two and Five

Systems two and five are estimated to have slightly poorer R&M characteristics than systems one, four and six due primarily to the greater exposure to damage associated with the soft-covered, externally mounted floats. The sponson floats will be particularly vulnerable to impact damage when the aircraft lands in unprepared areas and during ground handling. Daily inspections would be required to examine for damage to the covers; if damage were found, it would probably be necessary to unpack and inspect the float for tears and punctures, a time-consuming procedure.

Systems two and five also suffer the disadvantage of requiring the external fuel tanks to be jettisoned before deploying the sponson floats. They also suffer a significant disadvantage versus the other concepts in that failure to deploy either one of the two sponson floats will cause the aircraft to overturn and sink. Even without a malfunction of the flotation system, aircraft stability could be degraded if one of the two external fuel tanks fail to jettison, causing asymmetrical buoyancy.

System Three

System Three, the only six-float configuration, is estimated to have significantly worse R&M characteristics than any of the other five system concepts. It incorporates the soft-covered, externally mounted sponson floats and the increased maintenance they will require. Because of its complexity, system three has a greater probability of malfunction. Its one advantage is if any of the six floats fails to deploy, it will not roll over, although its stability would be decreased.

6.3 System Weight

The weight of each system is given in Table VI. Systems two and five are the lightest with the next lightest solution being the four float configurations mounted on the fuselage (systems one, four and six). Most of the weight increase for the four float fuselage system is due to structural modification and new electronics bay door required for mounting the floats internally in the aircraft. Mounting the floats inside improves the reliability and reduces the maintenance requirements for each system. As would be expected the heaviest system is the six float configuration of system three.

6.4 System Drag

The estimated drag of each system is presented in Table VI. As can be seen, the drag increments are small and would have a negligible effect on aircraft performance. The aft fuselage mounted floats are stowed internally and do not contribute any drag. The sponson floats contribute to the drag since their soft packaging extends outside the original sponson contours. The nose floats are packaged inside the electronics bay doors. These doors are "bumped out" to accommodate the floats, and therefore contribute a slight drag penalty.

6.5 System Cost

The relative cost factor of each system is presented in Table VIII. The relative cost factor is based on a preliminary estimate of each system normalized by system one. The recurring cost factor includes the cost of modifying each aircraft, tooling, maintenance, receiving and transfer inspection of each aircraft and materials required for the installation of the float system. Engineering design, qualification ground and flight testing, trial installation, materials and float design is included in the non-recurring cost estimate.

Comparative Initial Costs

Configurations two and five, the four float configuration with sponson floats, have a slightly lower recurring and non-recurring cost factor than the other four float configurations, systems one and four. It should be noted both four float configurations for sea state 4 have a higher non-recurring cost factor than their counterparts designed for sea state 5. This is due to the greater complexity of these systems because a larger number float compartments is required to provide stability with one compartment failed. The recurring cost factor for sea state 4 is lower than the counterpart designed for sea state 5 due to smaller size floats.

Due to its complexity the six float configuration, system three, has the highest cost factor. System six has the lowest cost factor due to its simplicity. However, system six does not provide stability with one float failed. If this capability were to be provided, system six floats would require a large number of compartments and the cost factor would increase.

Comparative Life Cycle Costs

The comparative life cycle cost factor for each system is also given in Table VIII. The reliability, maintainability, weight, drag and cost of each system previously discussed were included in the life cycle cost analysis. This analysis was based on thirty aircraft. As would be expected the life cycle cost factor of system six is the lowest and system three is the highest. The life cycle cost factor of system two and five is lower than the comparable four float systems one and four.

One important point to be noted is that a reduction in designed sea state capability results in only a small reduction in life cycle costs.

6.6 Final System Selection

Even though systems two and five have a slightly lower life cycle cost factor than systems one and four, the four fuselage float system one and four were selected for the final design phase of this study. This selection was based primarily on the improved safety characteristics of these two systems. With the floats mounted internally in the fuselage they are protected from ground handling and damage during water landings. In addition, the external auxiliary fuel tanks will not interfere or damage the floats during their inflation if they are not jettisoned prior to landing. These systems will also be compatible with the enlarged sponsons being proposed for the CH-53E without modification to the sponson design or modification to the float tooling. Also, as previously discussed, a float deployment failure will result in the aircraft rolling inverted but staying afloat with systems one and four. In systems two and five, float deployment failure will cause the aircraft to overturn and sink.

7.0 DETAIL DESIGN

The trade-off study resulted in the selection of systems one, four, and six for design sea state conditions of 5, 4 and 2 respectively. These systems all have the same basic layout, utilizing two floats forward and two aft. The float size and number of compartments within each float vary with each system.

This section provides a description of the detail features of the three systems, including physical characteristics, performance decrements, maintenance requirements, and approximate cost. One major change between these systems and the preliminary designs was the addition of auxiliary support tubes between the floats and the aircraft fuselage. These tubes distribute the float loads to maintain the bearing stresses on the fuselage structure at acceptable levels.

Three views of the final systems are given in Figures 28, 29, and 30. System characteristics and specifications are summarized in Tables IX, X, XI, and XII.

An alternative system which would allow the installation of the AN/ALE-29 Chaff Dispenser and have the same capabilities as system one is also discussed in this section. This configuration has been designated as system seven and is shown in Figure 31.

7.1 Physical Description

Geometry

As previously mentioned, all three systems utilize the same basic four float configuration. The forward floats are mounted on each side of the nose, directly under the cockpit. The aft floats are mounted on each side of the fuselage, just aft of the sponsons. The detailed float characteristics are given in Table IX.

Packaging

Both forward and aft floats are housed internally in the aircraft. The nose floats are stored within the electronics bay compartment door. This requires a new five-ply fiber glass door with an external blister and a modification to the latching system and hinges to react the loads produced by the floats. A four-ply fiber glass breakaway door cover provides protection for the floats from the elements and possible damage during ground handling. The door cover is attached to each float by a lanyard to retain it following inflation.

The aft floats are packaged in a five-ply fiber glass box approximately 50.8 x 102 x 15.2 cm (20 x 40 x 6 in.) with a four-ply fiber glass cover. Both box and cover utilize strux stiffeners. The cover is attached to the float by a lanyard to allow its recovery following inflation. These aft float compartments are installed in a 50.8 x 102 cm (20 x 40 in.) cutout between frames at FS 13.26m (522 in.) and FS 13.83m (544.5 in.). An intercostal is added between the frames from FS 12.75m (502 in.) to FS 14.40m (567 in.). The lower longeron and the frames at FS 13.26m (522 in.) and FS 13.83m (545.5 in.) would be strengthened to react float loads. In addition, doublers would be added around the cutouts. A drain line on the port side of the aircraft and an electrical line on the starboard side would have to be rerouted.

Materials

The floats would be constructed of rip-stop urathane-coated-nylon 0.0406cm (0.016 in.) thick. Additional layers of material are provided in areas where abrasion resistance are required, such as around the opening of the float compartments and where the forward floats would contact the rear view mirrors on the MH-53E version.

Auxiliary Support Tubes

Auxiliary support tubes were added to the upper inboard side of all floats to distribute the float loads more evenly and thereby maintain the bearing stresses on the fuselage at acceptable levels. These auxiliary tubes are 76 cm (30 in.) in diameter and the same length as their parent float. As a by-product, the presence of these tubes will help the floats to maintain their shape as they are submerged.

Inflation System

Each float is inflated with helium from its own separate fiberglass bottle and designed to operate at pressures between 8.62 kPa (1.25 PSI) and 24.1 kPa (3.5 PSI). Each inflation bottle is cylindrical and made of wound fiber glass for improved ballistic tolerance. Each bottle assembly contains a bottle, pressure gauge, relief valve, inflation valve, electrically actuated squib for rupturing a diaphragm to release the inflation gas, and a port which is connected to a line running to a manifold. The manifold has separate lines to each float compartment. As discussed previously, each compartment has a check valve to retain pressure if one of the other compartments burst. In addition, the check valve incorporates an orifice to choke the flow during inflation so that a failed compartment will not allow all of the inflating gas to escape.

The squibs are wired to a control panel in the cockpit. This control panel would be similar to that used on the SEAHAWK (SH-60B) and incorporate a guarded arming switch, a firing switch, and a test circuit.

Buoyancy and Stability

Buoyancy and stability characteristics of the final systems are summarized in Tables X and XI. As can be seen, all systems provide excess buoyancy, even with the critical compartment failed. A comparison of Tables VI and IX shows that the total buoyancy of each system has been increased due to the presence of the auxiliary support tubes.

The hydrodynamic stability characteristics of the final systems are the same as those used in the preliminary design. Figures 22, 25, and 27. The effect of the auxiliary support tubes on stability have not been considered for conservatism. Systems one and four have a reduced sea state capability with the critical compartment failed. System six does not have any capability with a failure, since providing that feature would have required either a large number of compartments per float, or floats with a sea state capability greater than the design value of two. Recall that all these stability characteristics are for cases with the cabin flooded.

7.2 Performance Decrements

The aircraft's performance is effected by both the increases in weight and in drag due to having the flotation systems installed.

Effect of Drag

The small parasite drag increase of 0.056m^2 (0.6 ft^2) will have a negligible effect on performance. At the best range speed of 241 km/hr (130 kts), the increase in power required is only 1.49 kw (2 HP) and this is equivalent to only 0.45 kg (1 lb) of fuel over a 278 km (150 nm) range mission. This increase in drag will not reduce the maximum speed capability of the CH-53E at its design gross weight since this value is determined by structural limits, not power limits.

Effect of Weight

The increase in weight due to the flotation system is more significant. Under power limiting hovering conditions payload or fuel will be reduced by an amount equal to the weight change if the aircraft is required to hover at a fixed altitude. Alternatively, if the hovering altitude capability is of importance, the higher gross weight will reduce the hover ceiling by approximately 79-131m (260-430 ft) depending on ambient conditions. The effect of weight on mission range depends, again, on the type of mission. For a mission at a fixed maximum Takeoff Gross Weight (T.O.G.W.) condition, the equivalent fuel reduction to allow for the flotation system weight would reduce a 278 km (150 nm) range by approximately 23.2 km (12.5 nm). For a 278 km (150 nm) range mission at a TOGW less than the maximum, the range would be reduced by approximately 0.83 km (0.45 nm) or the fuel for the same range would increase by 5.4 kg (12 lb.).

7.3 Maintenance Requirements

The following maintenance effort will be required to provide reliable service from each system:

1) Each day a walk-around inspection of the float compartments should be made to determine if they have been damaged. If there is damage to the compartment the float should be examined further and replaced if necessary. The helium pressure level in each bottle should be checked daily and if necessary they should be recharged.

2) Every 180 days a functional check of the system is required. the floats should be deployed and checked for leaks. Repairs should be made to the floats if required. The floats will then be deflated, dusted with talc and repacked until the next functional inspection. At this time system lines and hoses should be checked for wear, leakage and security of attachment. The manifold, fittings, bottles and pressure gage should be checked for cracks and corrosion and necessary repairs should be performed at this time.

3) Every three years the squib will be required to be replaced.

The type of maintenance that can be performed at the organizational, intermediate, and depot levels are listed below:

Organizational Level

- Remove and replace inflation bottle and valves
- Remove and replace the manifold
- Remove and replace the float assembly
- Remove and replace lines and hoses
- Remove and replace flotation system control panel
- Remove and replace pneumatic valve
- Remove and replace pressure gage
- Fault isolate the control and indicating system
- Perform minor repairs to the flotation system control panel.

Intermediate Level

- Repack and stow the float assembly
- Repair the float assembly
- Fault isolate the flotation system control panel
- Repair the flotation system control panel
- Perform functional test of the flotation control panel

Depot Level

- Repair the inflation bottles and valve assembly

7.4 Appropriate Cost Comparison of Systems

An approximate cost comparison based on 1981 dollars for developing, procuring and installing each system is presented in Table XIII. As can be seen there is little difference in the cost of developing, procuring and installing each system. The largest savings in procuring cost exists between system four and six (sea state 4 and 2 requirements) due to the smaller size floats and simplicity of system six. Based on this cost estimate it is concluded there is little savings in total system cost between sea state requirements for the multicompartment system. If multicompartment requirement is eliminated, there is a moderate reduction in the cost of the system.

7.5 Alternate System Design

During the detail design phase of this study an Engineering Change Proposal (ECP) was received from the U.S. Navy, Reference 2, to incorporate a chaff dispenser in the CH-53E. The location selected for the chaff dispenser is just aft of the main sponson. This is precisely where the aft floats for the three final configurations are located. It is beyond the scope of this contract to incorporate the chaff dispenser in this study. However, the effects on performance, relative cost and reliability of moving the aft floats of system one further aft and mounting them externally on the side of the aircraft were examined.

The alternate location for the rear floats is shown in Figure 31, and this configuration is designated System Seven. The total buoyancy and hydrodynamic stability of this system will remain essentially the same as system one. Mounting the rear floats externally will save weight but the drag of the system will increase slightly. The relative recurring cost will be less due to the reduction in tooling required for the installation of the aft floats, but their external mounting will increase failure rate and unscheduled maintenance requirements. The effect of this increase will be to balance the lower non-recurring cost of this system so that the relative life cycle cost of system one and seven are essentially the same.

The survivability characteristics of system one and seven are the same. If one float does not deploy the aircraft will roll over but will not sink.

A comparison of systems one and seven is provided in Table XIV.

8.0 SCALE MODEL DESCRIPTION

A 1/10 Froude-scaled model of the CH-53E helicopter has been constructed to allow an evaluation of the hydrodynamic characteristics of the aircraft with the three flotation systems selected by this study. Figure 32 shows a profile view of the model, while a top view is shown in Figure 33. The model was constructed primarily from fiber glass and balsa wood and incorporates a number of features which will allow for comprehensive hydrodynamic testing. These features are:

1) A significant effort was made to scale the weights of each of the major components (fuselage, empennage, tail pylon, main and tail rotor, landing gear and floats) to those of their full scale counterparts. This not only guaranteed that the total model weight would be correct, but that the model center-of-gravity and moments-of-inertia would also be scaled properly.

2) The personnel door, cargo ramp, and upper cargo door may be opened or sealed to allow evaluation of the aircraft with the cabin sealed or flooded.

3) The rotor blades are represented with the correct number, radius, and static droop. This insures that the effect of rotor contact with the water is correctly simulated.

4) Detachable floats for all three systems selected by the design study are available. Both forward and aft floats for Systems One and Four have removable compartments so that the effect of single compartment failures can be studied.

5) Provision for instrumentation (e.g., pitch and roll gyro) has been made on an upper deck which should be out of the water and is conveniently accessible.

6) A counterweight system is mounted in the cabin and allows for variations in gross weight, center-of-gravity location, and moments-of-inertia.

7) The landing gear may be fixed in the down position or removed to simulate gear up landings.

The model has been designed to be impervious to water. Access to the instrumentation and counterweights is provided through an access panel in the top of the fuselage. A detailed description of the model is provided below.

8.1 Model Description

Fuselage and Sponsons

The fuselage shell was constructed in two halves (port and starboard) by molding five layers of 0.025 cm (0.010 in.) thick fiber glass over a 1/10 scale mandrel of the CH-53E. Each half was removed from the mandrel, trimmed and then the two halves were bonded together to form a completely watertight shell. The sponsons were molded integrally with the fuselage contours. The engine nacelles were not included since they make no contribution to vehicle hydrodynamics, but their weight and inertia were properly accounted for. An access panel was cut into the top of shell between FS 6.18 cm (243.6 in.) and FS 11.68m (460 in.) at WL 4.32m (170 in.) as shown in Figure 32. An internal doubler was provided around the opening so the access panel could be attached to the model with screws.

A cabin floor was made from styrofoam and covered with three plys of 0.025 cm (0.010 in.) fiber glass. It was bonded into the fuselage at the correct scale height. This construction insured that the sealed volume of the fuselage "tub" was correctly modeled. The floor also acts to stiffen the fuselage and provides a mounting location for the counterweight assembly.

The sponsons were sealed internally to provide the correct watertight volume. In addition, the main landing gear wells were molded from three layers of 0.025 cm (0.010 in.) fiber glass and bonded into the sponsons. A balsa block, sealed with one layer of fiber glass, was bonded into each of the wells to act as a mounting poin for main landing gear. The nose landing gear well was constructed in the same way and bonded into a cutout at the appropriate location in the nose.

The personnel door, cargo ramp, and upper cargo door were simulated as shown in Figure 34. Appropriate cutouts were made in the fuselage while the doors were made from the fuselage knock-outs. These doors may be removed to allow cabin flooding or taped in place for studies requiring a sealed cabin. An upper deck was made from two plys of 0.025 cm (0.010 in.) fiber glass and bonded in place in the upper portion of the fuselage as shown in Figure 32. This deck serves as the mounting point for the main rotor assembly and provides space for the instrumentation well above any anticipated water level.

The landing gear was carved from wood and is detachable. If removed to simulate a gear up condition, its weight must be compensated for.

Tail Pylon, Empennage, and Tail Rotor

The tail pylon is a carved block of solid balsa, hollowed out and covered with one layer of 0.008 cm (0.003 in.) fiber glass. The horizontal and vertical tails were carved out of balsa and covered with one-ply of 0.008 cm (0.003 in.) fiber glass. A plexiglass disk was used to model the tail rotor. The complete tail assembly is bonded to the fuselage.

As noted before, the weights of the tail rotor, horizontal and vertical tails, and the tail pylon were kept as close as possible to the scale values of the actual aircraft.

Main Rotor Assembly

The main rotor assembly is shown in Figure 35. The blades are simulated with aluminum channels since no attempt was made to model their aerodynamic contours. These channels are bent to provide the same static droop as the actual blades and, of course, there are seven blades of the correct scale radius so that the rotor contact envelope with water is correctly modeled.

The rotor blades are bolted between two aluminum disks to form the envelope of the rotor while a steel weight is used to simulate its mass. This counterweight and rotor itself fit over a threaded steel rod which has been welded to a mounting plate with the correct shaft tilt of five degrees. This entire assembly bolts onto the upper deck in the fuselage.

Counterweight System

The gross weight, center-of-gravity (c.g.) location, and moments-of-inertia of the model can be varied using a counterweight system shown in Figure 36. This consists of a long threaded steel rod supported on a steel mounting plate which is bolted to the cabin floor.

Gross weight is adjusted by selecting the number of weights to be used. Longitudinal c.g. is adjusted by selecting the fore and aft location of the weights, while lateral c.g. offsets are modeled by sliding the entire assembly sideways. Vertical c.g. adjustment is made by sliding the counterweight rod up or down within the slots provided.

Roll inertia can be varied by adjusting the weight distribution between the counterweight assembly and the rotor head weight. Pitch inertia can be adjusted by varying the longitudinal weight distribution on the threaded rod. The yaw inertia will vary as the pitch inertia is adjusted, but experience has shown that yaw inertia scaling is not nearly as important as pitch and roll.

Floats

Floats for all three final designs (systems one, four, and six) were constructed for use with the helicopter model (see Figures 37 and 38). The floats were cut from styrofoam, hollowed out, and covered with a 0.008 cm (0.003 in.) fiber glass skin for protection. The floats are attached to the fuselage in the appropriate location with through-bolts. Both the forward and aft floats for systems one and four have removable compartments so that the hydrodynamic stability with a failed bag compartment can be studied.

It should be noted that the model floats have smaller than scale diameters so that their buoyancy is 75 percent of the free volume value. In this way, the buoyancy and stability characteristics of the model and the analysis are comparable.

8.2 Model Characteristics

The basic model characteristics are given in Table XV. The total weight and c.g. location of the model without the counterweights is given in the last column. The scale values of weight, c.g. locations and inertia for the study configuration are in the middle column.

8.3 MH-53E Simulation

It may be desirable to study the hydrodynamic characteristics of the MH-53E with enlarged sponsons at some time in the future. The existing CH-53E model can be used essentially as is. The current intention is that oversize sponsons would be constructed so as to fit over the existing ones. This would allow the MH-53E to be studied without destroying the integrity of the CH-53E model. In this case, the auxiliary tank support pylons would have to be removed from the existing model.

9.0 CONCLUSIONS

9.1 The CH-53E is stable in sea state 2 with the cabin sealed. No auxiliary flotation is required.

9.2 The CH-53E requires both additional bucyancy and additiona stability to float upright in sea state 2 with the cabin flooded.

9.3 After an autorotative landing, s .'ficient main rotor control is available to keep the aircraft upright for approximately six seconds. This is sufficient to allow full deployment of the auxiliary flotation bags if helium is the inflating medium.

9.4 The best method for prov.'ding additional buoyancy and stability is the use of inflatable, au. .iary flotation bags.

9.5 The best auxiliary flotation bag configuration utilizes four fuselage mounted floats, two forward and two aft. Such a system can provide all the required buoyancy and insure stability in sea states from 2 to 5. Sea state capability depends on bag size selected.

9.6 Increasing system capability from sea state 2 to sea state 5 increases system cost. only slightly.

9.7 An auxiliary flotation system utilizing inflatable bags can provide the CH-53E with buoyancy and hydrodynamic stability to sea state 5 conditions. Such a system would have a small weight penalty, acceptable reliability and maintainability, and minimal effect on aircraft performance.

10.0 RECOMMENDATIONS

10.1 The scale model CH-53E constructed by Sikorsky should be used to validate the results of this study.

10.2 An analysis should be conducted to determine the effect of each of the final design systems on CH-53A/D sea keeping qualities.

10.3 An analysis of the basic hydrodynamic characteristics and sea state capability of the C/MH-53E with enlarged sponsons should be conducted.

10.4 A scale model of the C/MH-53E with enlarged sponsons should be hydrodynamically tested. This model could be a modified version of the CH-53E model constructed for this study.

11.0 REFERENCES

1. Lowry, D.W.; Pisano, J.; Olson, J. "CH-53A Hydrodynamic Loads and Hydrodynamic Stability", SER-50296, 16 May, 1963.

2. ECP 2006R1, Authorized 30 October 1980.

TABLE I

CH-53E BUOYANCY CHARACTERISTICS

WITHOUT FLOODING

WATER-LINE m (in)	FUSELAGE "TUB" kg (lb)	NOSE "TUB" kg (lb)	CABIN kg (lb)	SPONSON kg (lb)	TOTAL BUOYANCY kg (lb)
2.21 (87)	0 0	0 0	0 0	0 0	0 0
2.46 (97)	5473 (12066)	381 (841)	0 0	609 (1342)	6463 (14,249)
2.72 (107)	5473 (12066)	900 (1985)	6900 (15,212)	2635 (5809)	15908 (35,072)
2.97 (117)	5473 (12066)	1505 (3319)	14249 (31,414)	5072 (11,181)	26299 (57,980)
3.26 (127)	5473 (12066)	2164 (4772)	21912 (48,309)	7174 (15,815)	36723 (80,962)
3.48 (137)	5473 (12066)	2880 (6371)	29935 (65,996)	8055 (17,759)	46353 (102,192)

TABLE II

CH-53E BUOYANCY CHARACTERISTICS

WITH FLOODING

WATER-LINE m (in)	FUSELAGE "TUB" kg (lb)	NOSE "TUB" kg (lb)	CABIN kg (lb)	SPONSON kg (lb)	TOTAL BUOYANCY kg (lb)
2.21 (87)	0 0	0	0	0 0	0 0
2.46 (97)	5473 (12066)			609 (1342)	6082 (13408)
2.72 (107)	5473 (12066)			2635 (5809)	8108 (17875)
2.97 (117)	5473 (12066)			5072 (11,181)	10545 (23247)
3.26 (127)	5473 (12066)			7174 (15815)	12647 (27881)
3.48 (137)	5473 (12066)			8055 (17759)	13528 (29825)

TABLE III

CH-53E ROLLING MOMENT PARAMETER

WATERLINE m (in)	ROLLING MOMENT PARAMETER m^3 (ft^3)
2.46 (97)	138.6 (4896)
2.72 (107)	123.4 (4357)
2.97 (117)	108.9 (3845)
3.26 (127)	95.26 (3364)
3.48 (137)	82.52 (2914)

TABLE IV

HYDROSTATIC WIND MOMENT REQUIREMENT

SEA STATE CONDITION	HYDROSTATIC WIND REQUIREMENT	HYDROSTATIC MOMENT REQUIRED N-m (Ft-lbs)				
	m/sec (Kts)	WL 2.46	WL 2.72	WL 2.97	WL 3.26	WL 3.48
5	40.3 (78.3)	137913 (101719)	122733 (90523	108307 (79883)	94760 (69891)	82087 (60544)
4	26.0 (50.6)	57404 (42339)	51085 (37678)	45081 (33250)	39442 (29091)	34167 (25200)
3	19.6 (38.2)	32622 (24060)	29031 (21412)	25619 (18896)	22414 (16532)	19417 (14321)
2	12.9 (25.0)	14131 (10422)	12576 (9276)	11097 (8185)	9709 (7161)	8411 (6204)

TABLE V

BASIC CHARACTERISTICS OF CA

System Number	Design Sea State	No. of Floats	No. of Components	FORWARD FLOATS			No. of Components	AFT FL	
				Dia. m (ft)	Length m (ft)	Buoy. kg (lbs)		Dia. m (ft)	Len m (f
1	5	4	3	1.83 (6.0)	2.13 (7.0)	4206 (9273)	3	1.83 (6.0)	2. (8.
2	5	4	-	- -	- -	- -	2	1.19 (3.9)	1. (5.
3	5	6	4	1.71 (5.6)	2.19 (7.2)	3769 (8308)	4	1.71 (5.6)	2. (8.
4	4	4	4	1.71 (5.6)	2.19 (7.2)	3769 (8308)	4	1.71 (5.6)	2. (8.
5	4	4	-	- -	- -	- -	2	1.19 (3.9)	1. (5.
6	2	4	1	1.74 (5.7)	2.01 (6.6)	3579 (7891)	1	1.74 (5.7)	2. (7.

TABLE V

BASIC CHARACTERISTICS OF CANDIDATE FLOATS

FORWARD FLOATS			No. of Components	AFT FLOATS			No. of Components	SPONSON FLOATS		
	Length	Buoy.		Dia.	Length	Buoy.		Dia.	Length	Buoy.
	m (ft)	kg (lbs)		m (ft)	m (ft)	kg (lbs)		m (ft)	m (ft)	kg (lbs)
	2.13 (7.0)	4206 (9273)	3	1.83 (6.0)	2.65 (8.7)	5227 (11,525)	-	- -	- -	- -
	- -	- -	2	1.19 (3.9)	1.62 (5.3)	1346 (2966)	5	1.54 (5.05)	5.33 (17.5)	7449 (16422)
	2.19 (7.2)	3769 (8308)	4	1.71 (5.6)	2.71 (8.9)	4659 (10,270)	2	1.07 (3.57)	2.68 (8.8)	1799 (3967)
	2.19 (7.2)	3769 (8308)	4	1.71 (5.6)	2.71 (8.9)	4659 (10,270)	-	- -	- -	- -
	- -	- -	2	1.19 (3.9)	1.62 (5.3)	1346 (2966)	7	1.49 (4.9)	5.18 (17.0)	6813 (15,019)
	2.01 (6.6)	3579 (7891)	1	1.74 (5.7)	2.41 (7.9)	4284 (9445)	-	- -	- -	- -

TABLE VI

BASIC CHARACTERISTICS OF CANDI

System Number	Design Sea State	System(1) Weight Kg (lbs)	System Drag m^2 (ft^2)	Total(2) Buoy. Kg (lbs)	Buoy.(2) Failed Comp. Kg (lbs)	Number of Bottles	Bo Vo Li (
1	5	200 (442)	.06 (.0056)	18,867 (41,595)	17,12[illegible] (38,7[illegible])	4	3 (2
2	5	181 (399)	.03 (.0028)	17,589 (38,777)	16,099 (35,492)	4	
3	5	244 (538)	.08 (.0074)	20,453 (45,090)	18,653 (41,124)	6	3 (1
4	4	196 (433)	.06 (.0056)	16,854 (37,157)	15,689 (34,590)	4	3 (1
5	4	180 (397)	.03 (.0028)	16,316 (35,971)	15,343 (33,826)	4	
6	2	191 (421)	.06 (.0056)	15,726 (34,670)	11,442 (25,226)	4	(

(1) System weight will increase by approximately 15% if nitroger inflation medium.

(2) Based on 75% of the free Volume.

TABLE VI

BASIC CHARACTERISTICS OF CANDIDATE SYSTEMS

Total(2) Buoy.	Buoy.(2) Failed Comp.	Number of Bottles	Forward Sys.		Aft Sys.		Sponson Sys.	
			Bottle Vol.	Line Size	Bottle Vol.	Line Size	Bottle Vol.	Line Size
Kg (lbs)	Kg (lbs)		Liter (in^3)	cm (in)	Liter (in^3)	cm (in)	Liter (in^3)	cm (in)
8,867 (1,595)	17,125 (38,777)	4	35.4 (2163)	2.54 (1.00)	43.8 (2670)	2.86 (1.13)	-	-
7,589 (8,777)	16,099 (35,492)	4	-	-	11.0 (672)	2.22 (.875)	62.7 (3826)	3.49 (1.38)
0,453 (5,090)	18,653 (41,124)	6	31.6 (1926)	2.54 (1.00)	38.9 (2372)	2.86 (1.13)	14.8 (906)	1.27 (0.50)
6,854 (7,157)	15,689 (34,590)	4	31.6 (1926)	2.54 (1.00)	38.9 (2372)	2.86 (1.13)	-	-
6,316 (5,971)	15,343 (33,826)	4	-	-	11.0 (672)	2.22 (.875)	57.0 (3480)	3.49 (1.38)
5,726 (4,670)	11,442 (25,226)	4	29.8 (1817)	2.54 (1.00)	35.8 (2182)	2.54 (1.00)	-	-

approximately 15% if nitrogen is used for

TABLE VII

NORMALIZED RELIABILITY AND MAINTAINABILITY RATINGS

SYSTEM	INSP. TIME	FAILURE RATE	UNSCHED. MAINT. MAN-HRS.	RELATIVE PROBABILITY		
				DEPLOYMENT FAILURE*	ROLLOVER INCIDENT	SINKING INCIDENT
1	1.05	1.0	1.0	1.0	2.0	1.0
2	1.10	1.15	1.10	1.0	3.0	**
3	1.45	1.45	1.45	1.5	1.0	1.0
4	1.05	1.0	1.0	1.0	2.0	1.0
5	1.05	1.15	1.10	1.0	3.0	**
6	1.0	1.0	1.0	1.0	2.0	1.0

*One bottle failing to discharge

**Insufficient buoyancy if sponson float fails

Notes:

1. Value 1.0 indicates best system relative to that attribute; higher values proportionately worse
2. Baseline Values:

   Inspection Time: 9.5 manhours ea. 180 days or 180 flight-hours

   Failure Rate: 3.5 failures/10^3 flight-hours

   Unscheduled Maintenance: 3.7 manhours/10^3 flight-hours

TABLE VIII

RELATIVE SYSTEM INITIAL AND LIFE CYCLE COSTS

SYSTEM	DESIGN SEA STATE	SYSTEM COSTS		
		INITIAL		LIFE CYCLE
		RECURRING	NON-RECURRING	
1	5	1.000	1.000	1.000
2	5	0.914	0.974	0.960
3	5	1.203	1.280	1.285
4	4	0.992	1.017	0.990
5	4	0.910	0.985	0.958
6	2	0.918	0.959	0.897

TABLE IX

FINAL SYSTEM DESIGN

FLOAT CHARACTERISTICS

PARAMETER	SYSTEM ONE (FINAL)	SYSTEM FOUR (FINAL)	SYSTEM SIX (FINAL)
FORWARD FLOATS			
No. of Compartments	3	4	1
Diameter, m (ft)	1.83 (6.0)	1.71 (5.6)	1.74 (5.7)
Length, m (ft)	2.13 (7.0)	2.20 (7.2)	2.01 (6.6)
Buoyancy*, Kg (lbs)	5182 (11,425)	4750 (10,471)	4452 (9816)
Location**			
FS, cm (in)	340.6 (134.1)	340.6 (134.1)	342.1 (134.7)
WL, cm (in)	233.2 (91.8)	221.0 (87.0)	216.4 (85.2)
AFT FLOATS			
No. of Compartments	3	4	1
Diameter, m (ft)	1.83 (6.0)	1.71 (5.6)	1.74 (5.7)
Length, m (ft)	2.65 (8.7)	2.70 (8.9)	2.41 (7.9)
Buoyancy*, Kg (lbs)	6405 (14,121)	5853 (12,809)	5347 (11,787)
Location**			
FS, cm (in)	1381 (543.7)	1386 (545.5)	1370 (539.2)
WL, cm (in)	288.3 (113.5)	280.7 (110.5)	271.8 (107.0)

NOTE: All auxiliary support tubes are 0.76m (2.5 ft) in diameter and the same length as their parent float.

* Based on 75% of the free volume.

**Center of Float

TABLE X

FINAL SYSTEM DESIGN

BUOYANCY SUMMARY

CONDITION	SYSTEM ONE (FINAL)	SYSTEM FOUR (FINAL)	SYSTEM SIX (FINAL)
NORMAL			
Floats, Kg (lbs)	23,175 (51,092)	21,206 (46,750)	19,598 (43,206)
Total, Kg (lbs)	36,446 (80,350)	34,477 (76,008)	32,869 (72,464)
% Study GW	149	141	134
CRITICAL COMPARTMENT FAILED			
Floats, Kg (lbs)	21,040 (46,385)	19,742 (43,524)	14,251 (31,419)
Total, Kg (lbs)	34,311 (75,643)	33,013 (72,782)	27,522 (60,677)
% Study GW	140	135	113

NOTE - Total buoyancy based on an aircraft buoyancy of 13,271 Kg (29,258 lbs.) with the cabin flooded.

TABLE XI

FINAL SYSTEM DESIGN

SUMMARY OF STABILITY CHARACTERISTICS

CONDITION	SYSTEM ONE (FINAL)	SYSTEM FOUR (FINAL)	SYSTEM SIX (FINAL)
NORMAL			
Sea State Capability	5	4	2
Maximum Righting Mom., N-m	70,900	37,500	11,000
(ft-lbs)	(52,293)	(27,659)	(8113)
@ Roll Angle, degrees	12	9	12
CRITICAL COMPARTMENT FAILED			
Sea State Capability	2	1	0
Maximum Righting Mom., N-m	10,000	2,000	-
(ft-lbs)	(7376)	(1475)	-
@ Roll Angle			

NOTE: Stability calculations based on the following assumptions:

1) Cabin flooded

2) Floats have 75% of their free volume

3) Aux. support tubes make no contribution to stability

TABLE XII

FINAL SYSTEM DESIGN

INFLATION SYSTEMS SUMMARY

PARAMETER	SYSTEM ONE (FINAL)	SYSTEM FOUR (FINAL)	SYSTEM SIX (FINAL)
FORWARD FLOATS			
No. of Bottles	2	2	2
Vol. per Bottle, liters	41.6	37.9	35.6
(in^3)	(2538)	(2311)	(2170)
Inflation Line Size, cm	2.54	2.54	2.54
(in)	(1.00)	(1.00)	(1.00)
AFT FLOAT			
No. of Bottles	2	2	2
Vol. per Bottle, liters	51.4	46.7	42.7
(in^3)	(3135)	(2849)	(2605)
Inflation Line Size, cm	2.86	2.86	2.54
(in)	(1.125)	(1.125)	(1.00)

NOTE: All systems have a design operating pressures of 20,684 kPa (3000 PSI).

TABLE XIII

FINAL SYSTEM DESIGN

COST ESTIMATE

	SYSTEM ONE (FINAL)	SYSTEM FOUR (FINAL)	SYSTEM SIX (FINAL)
DEVELOPMENT COST	2,150,000	2,153,000	2,146,000
RECURRING COST			
Procuring	49,700	51,400	42,000
Installation	100,300	102,200	97,500
TOTAL	150,000	153,600	139,500

TABLE XIV

COMPARISON OF SYSTEMS ONE AND SEVEN

SYSTEM ATTRIBUTE	SYSTEM ONE	SYSTEM SEVEN
WEIGHT, Kg	201	189
(lbs)	(442)	(416)
DRAG, m^2	.056	.065
(ft^2)	(0.6)	(0.7)
RELATIVE COST		
Recurring	1.00	1.00
Non-recurring	1.00	0.98
Life-cycle	1.00	1.01
RELIABILITY AND MAINTAINABILITY		
Inspection time	1.05	1.05
Failure Rate	1.00	1.10
Unscheduled Maintenance Man-hrs	1.00	1.10
Deployment Failure	1.00	1.00
Roll-Over Incidence	2.00	2.00
Sinking Incidence	1.00	1.00

TABLE XV

MODEL CHARACTERISTICS

PARAMETER	FULL SCALE VALUE	1/10 SCALE VALUE	MODEL AS DELIVERED*
Gross Weight, Kg (lb)	24,444 (53,889)	24.44 (53.89)	13.60 (30.00)
C.G. Location			
FSCG, m (in)	9.06 (356.7)	9.06 (356.7)	10.47 (412.3)
WLCG, m (in)	4.19 (165.1)	4.19 (165.1)	4.97 (195.6)
BLCG, m (in)	-048 (1.9)	.048 (1.9)	(0) (0)
Moments-of-Inertia			
I_{xx}, Kg-m^2 (slug-ft^2)	43,699 (59,248)	.4370 (.5925)	-
I_{yy}, Kg-m^2 (slug-ft^2)	230,317 (312,267)	2.3032 (3.1227)	-
I_{zz}, Kg-m^2 (slug-ft^2)	217,138 (294,398)	2.1714 (2.9440)	-

*Without Instrumentation

FIGURE 1   CH-53E REFERENCE COORDINATES

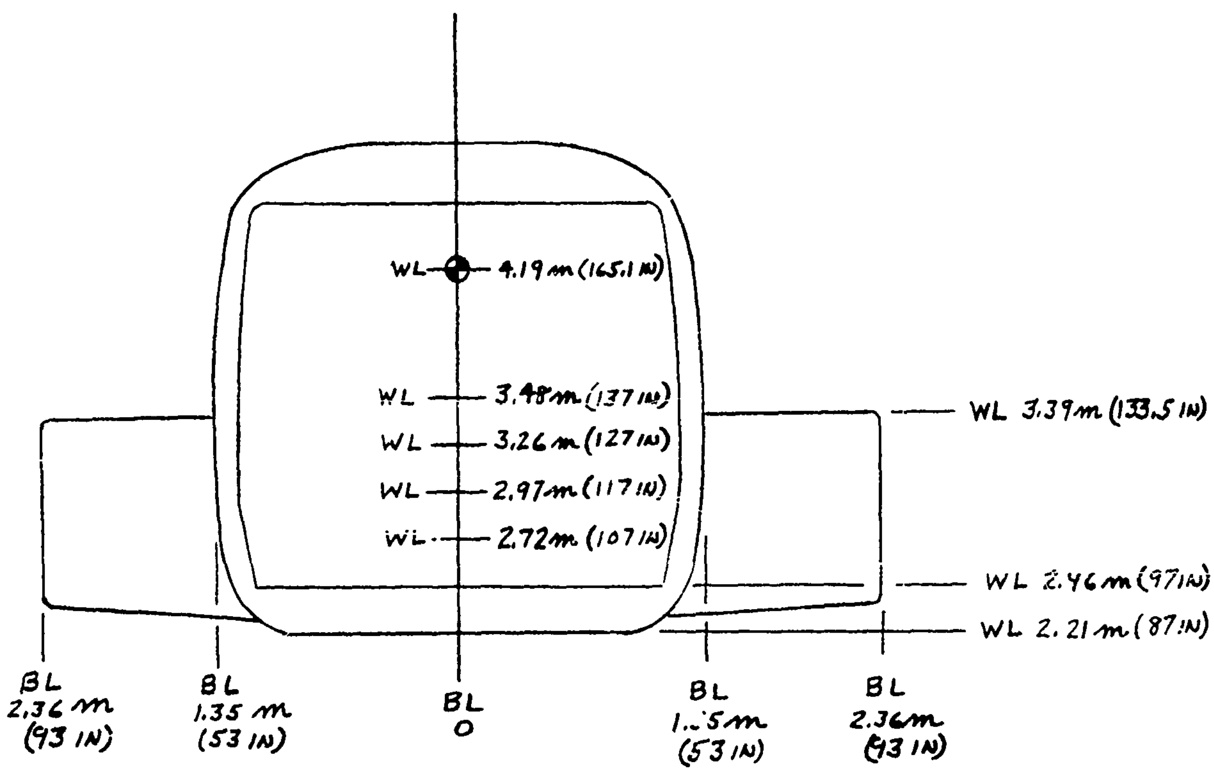


FIGURE 2 CH-53E BUOYANCY CHARACTERISTICS

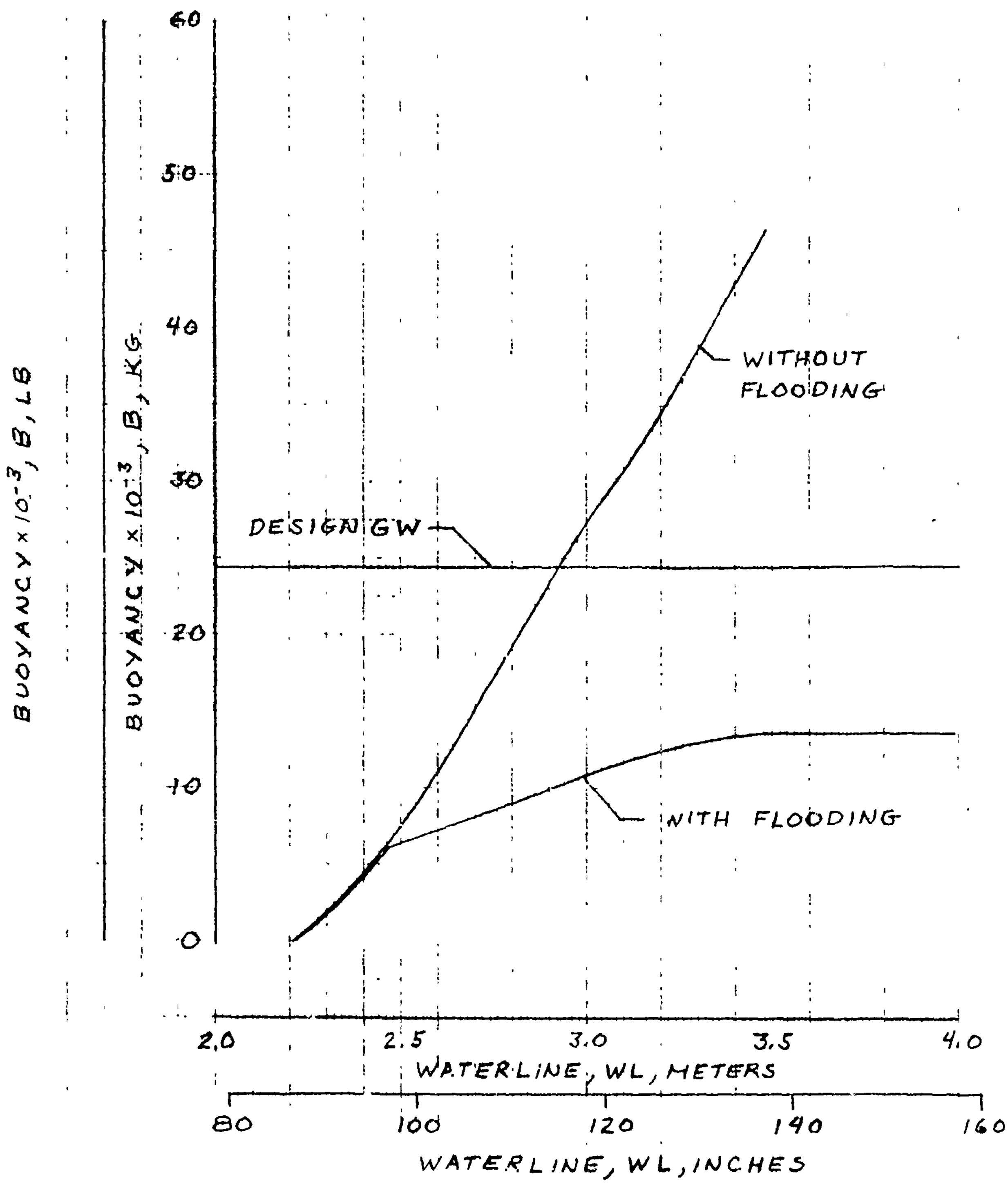


FIGURE 3 CH-53E ROLL ABOUT WATER LINE 2.97m

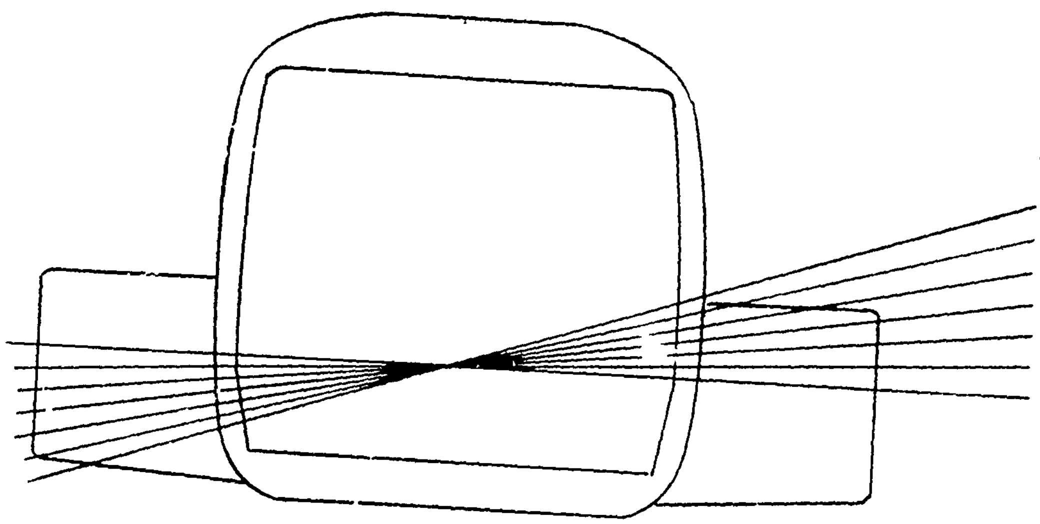
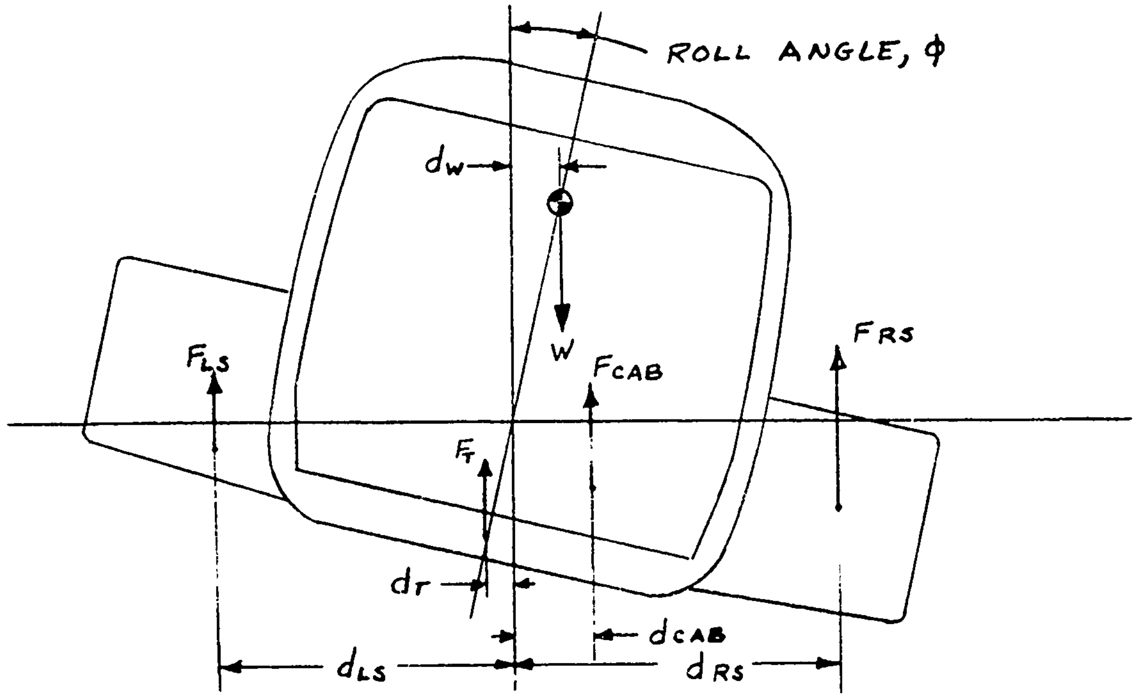


FIGURE 4 CH-53E RIGHTING MOMENT CALCULATION



F_{LS}, LEFT SPONSON BUOYANCY FORCE, N (LB)
F_{RS}, RIGHT SPONSON BUOYANCY FORCE, N (LB)
F_T, TUB BUOYANCY FORCE, N (LB)
F_{CAB}, CABIN BUOYANCY FORCE, N(LB)
W, AIRCRAFT WEIGHT, N(LB)
d_{LS}, LEFT SPONSON MOMENT ARM, m (FT)
d_{RS}, RIGHT SPONSON MOMENT ARM, m (FT)
d_T, TUB MOMENT ARM, m (FT)
d_{CAB}, CABIN MOMENT ARM, m (FT)
d_W, AIRCRAFT MOMENT ARM, m (FT)
$\mathcal{M}$, TOTAL RIGHTING MOMENT, N-m (FT-LB)

$$\mathcal{M} = F_{RS}\, d_{RS} + F_{AB}\, d_{CAB} - F_{LS}\, d_{LS} - F_T\, d_T - W\, d_W$$

FIGURE 5 CH-53E GROSS RIGHTING MOMENT WITHOUT CABIN FLOODING

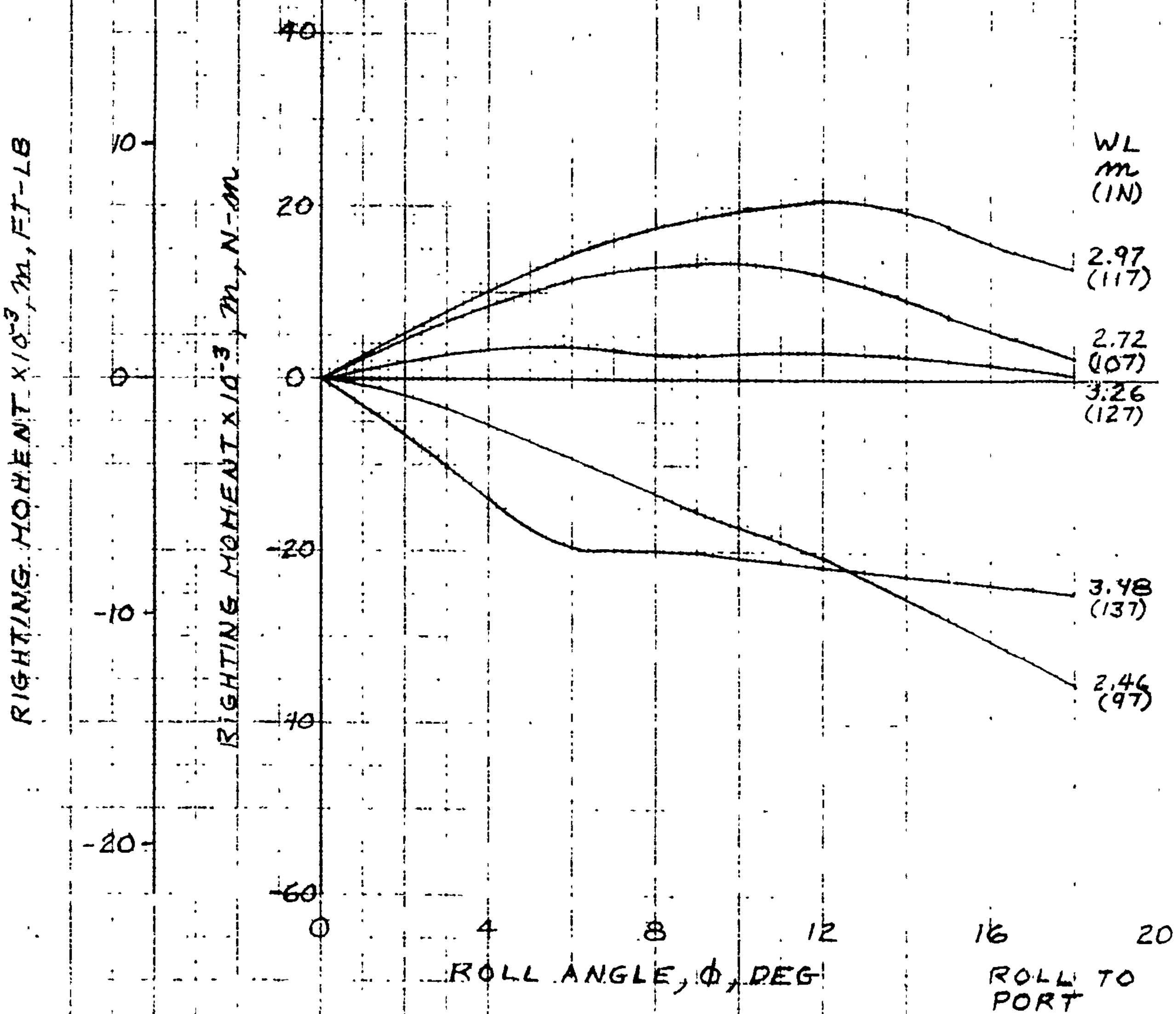


FIGURE 6 CH-53E GROSS RIGHTING MOMENT WITH CABIN FLOODING

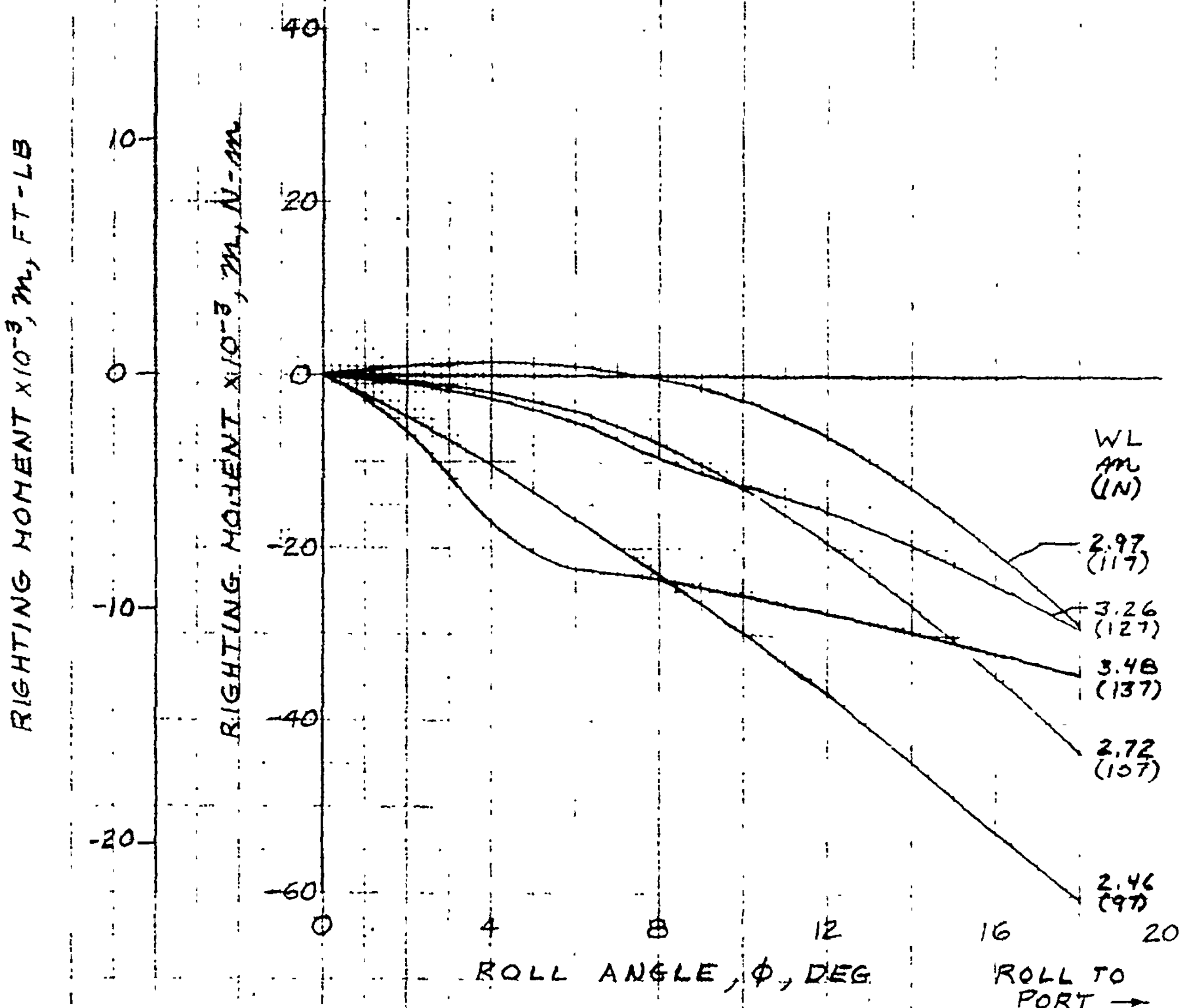


FIGURE 7 CH-53A SEA STATE CAPABILITY

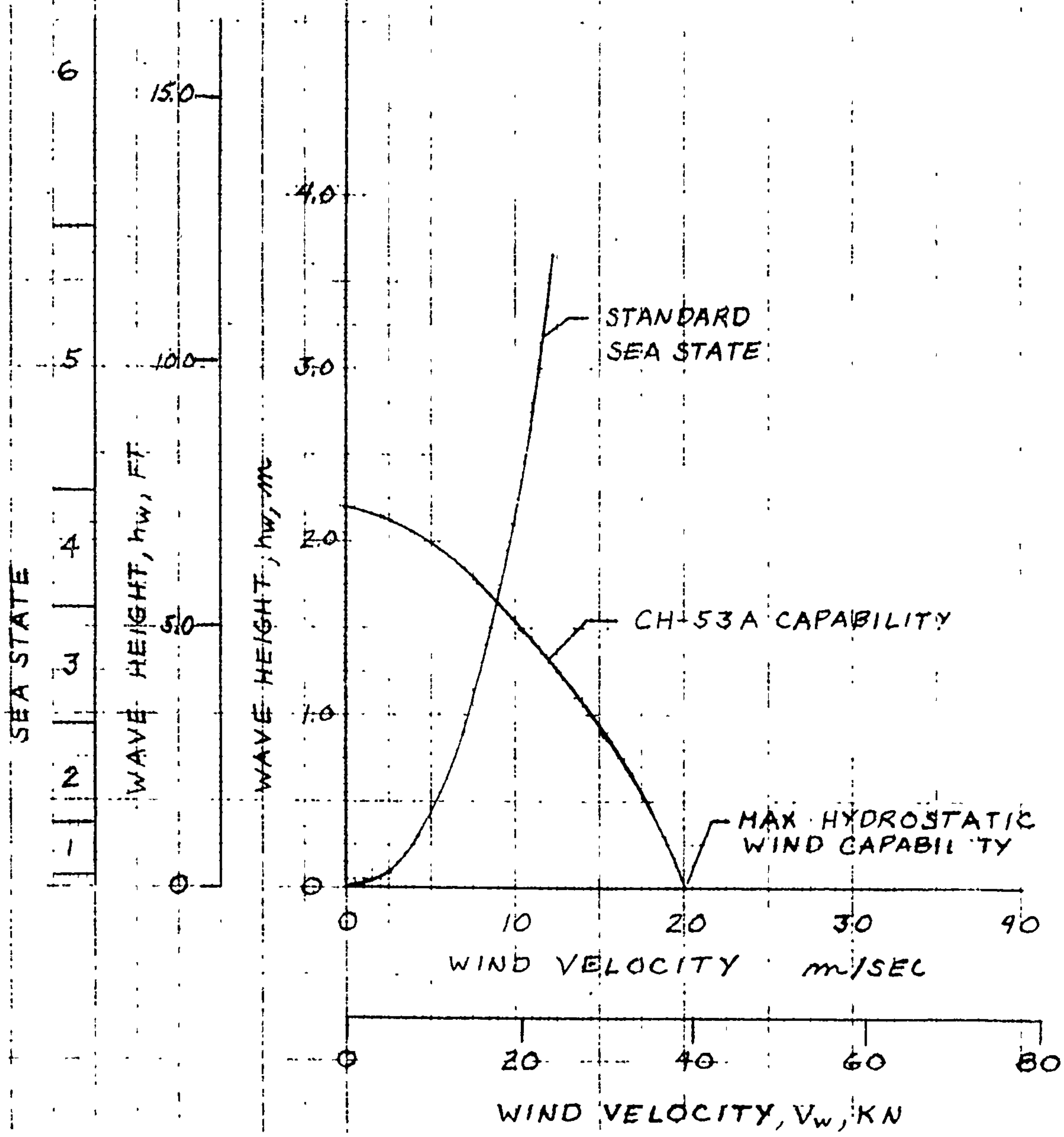
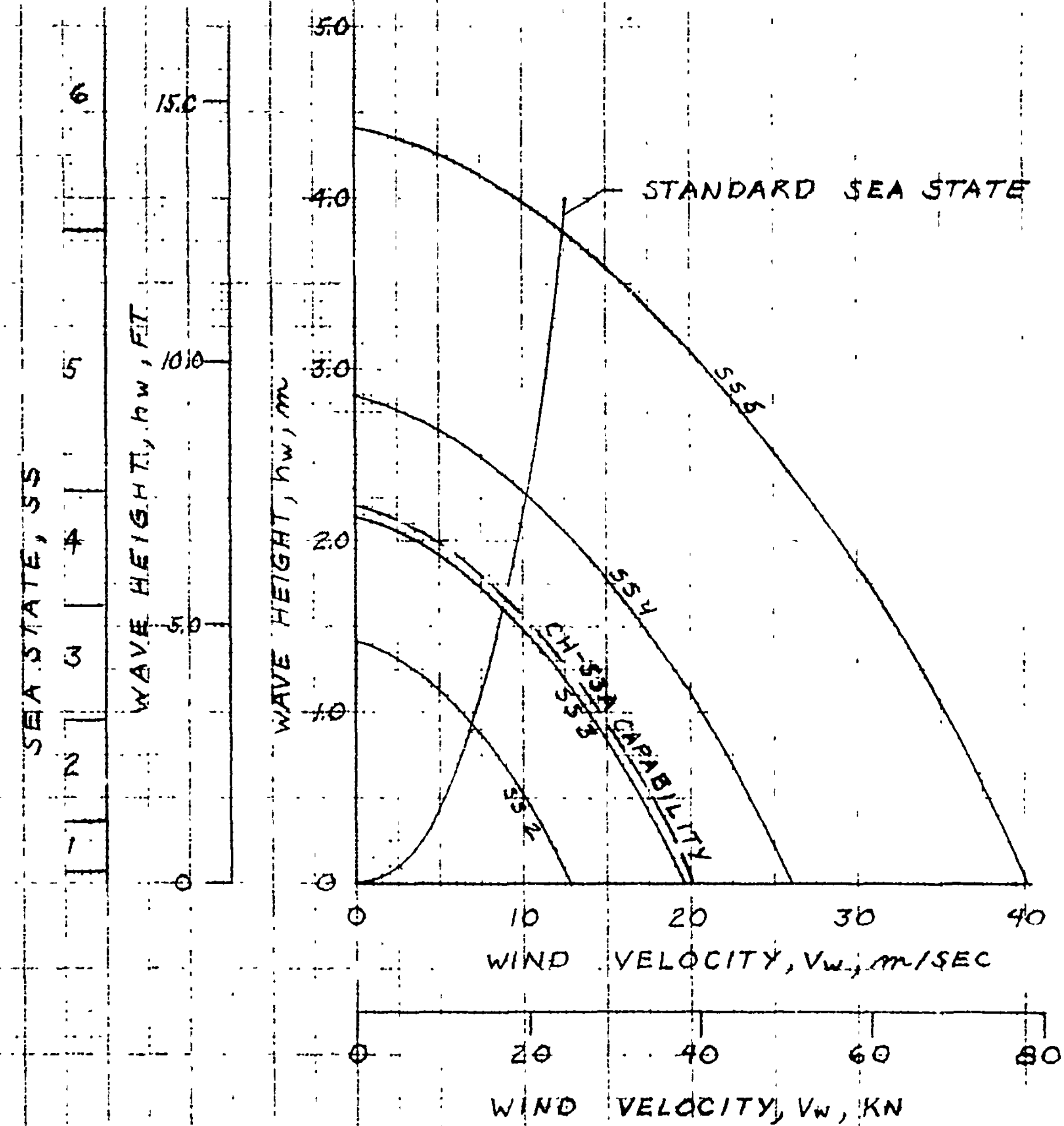


FIGURE 8 CH-53E HYDROSTATIC WIND REQUIREMENT VS SEA STATE



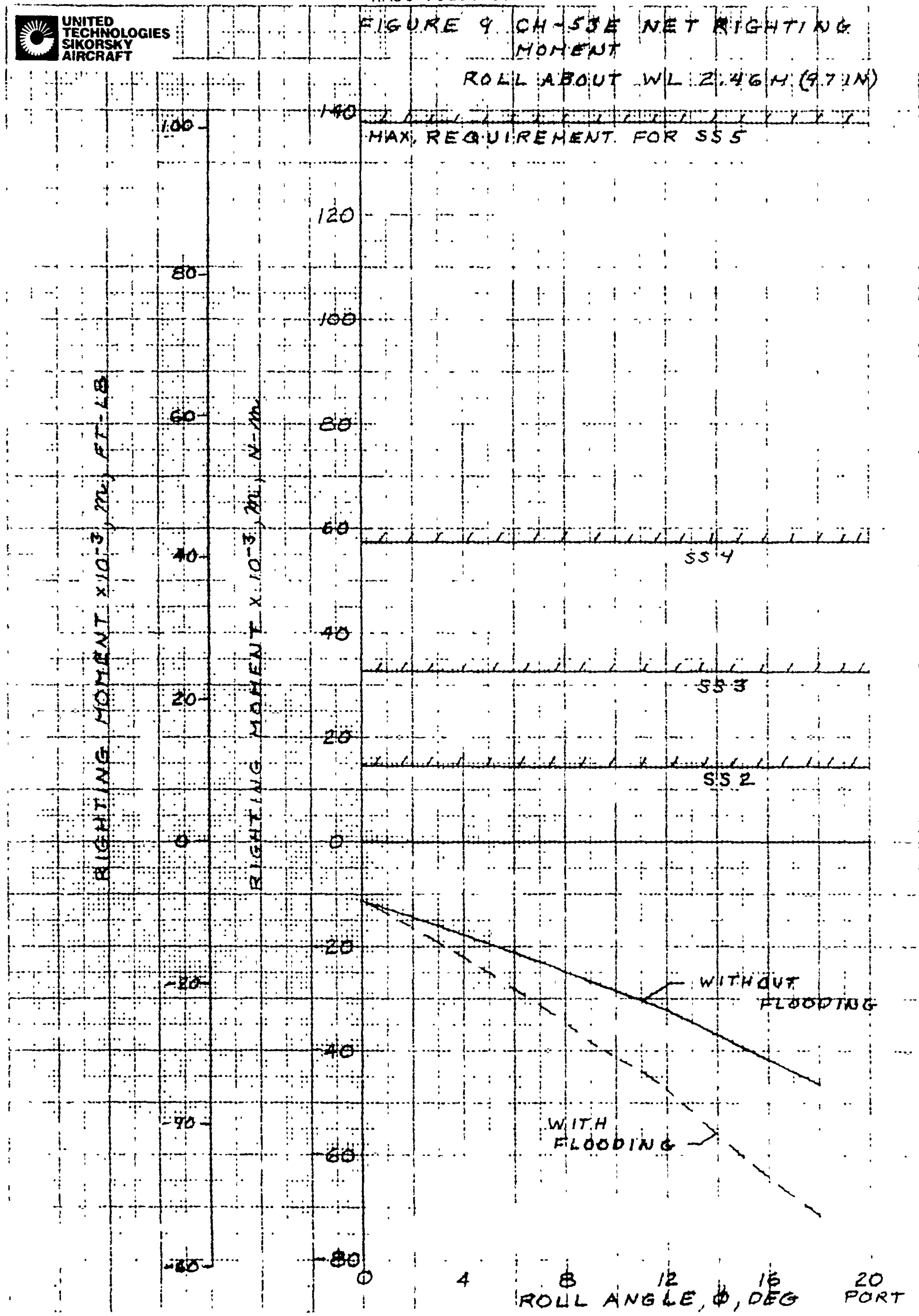

UNITED TECHNOLOGIES SIKORSKY AIRCRAFT
FIGURE 9 CH-53E NET RIGHTING MOMENT
ROLL ABOUT WL 2.46M (97 IN)
MAX. REQUIREMENT FOR SS5
SS 4
SS 3
SS 2
WITHOUT FLOODING
WITH FLOODING
RIGHTING MOMENT x 10⁻³, M, FT-LB
RIGHTING MOMENT x 10⁻³, M, N-m
100
80
60
40
20
0
-20
-40
140
120
100
80
60
40
20
0
-20
-40
-60
-80
0
4
8
12
16
20
ROLL ANGLE, Φ, DEG
PORT

FIGURE 10 CH-53E NET RIGHTING MOMENT
ROLL ABOUT WL 2.72 M (107 IN)

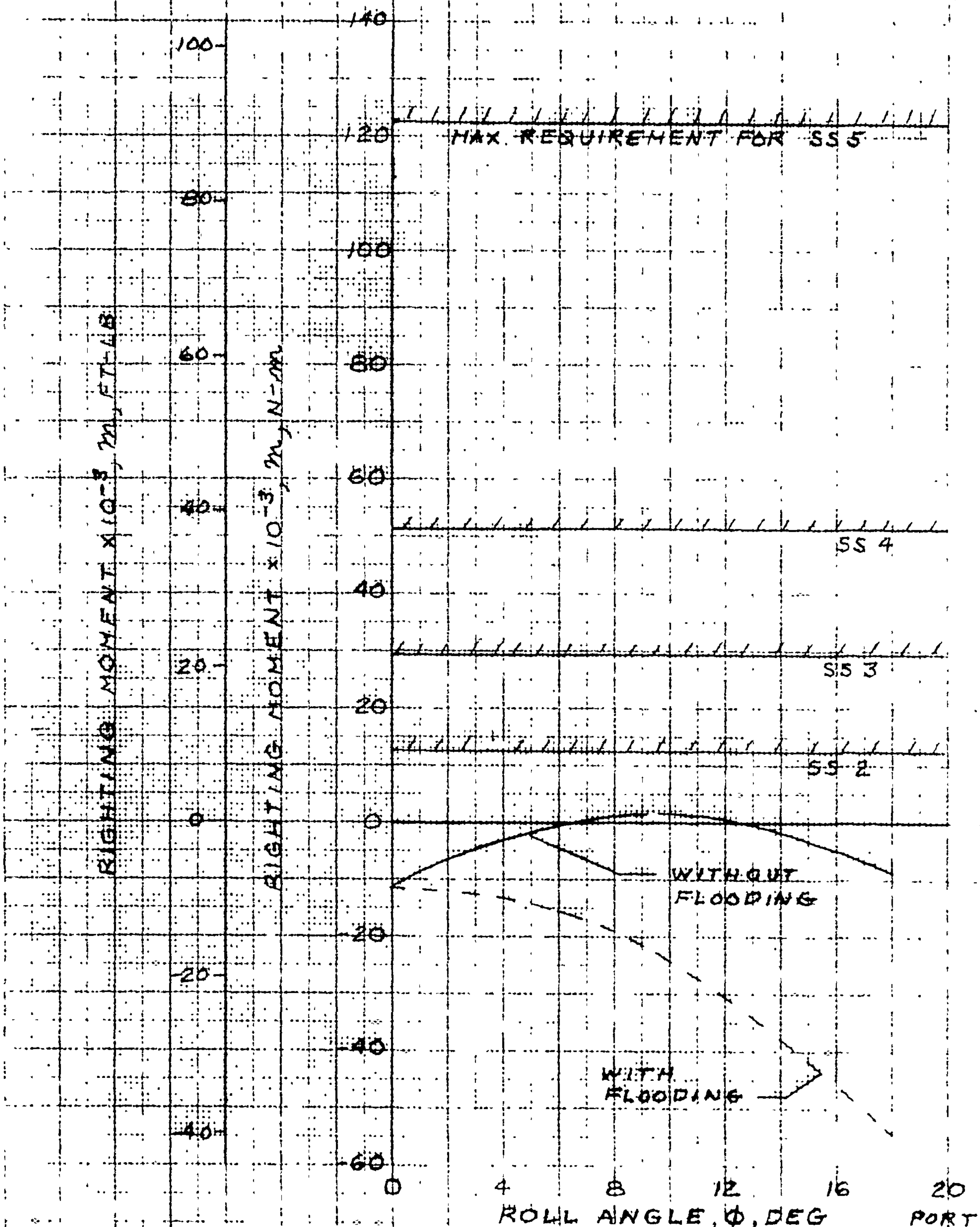


FIGURE 11 CH-53E NET RIGHTING MOMENT
ROLL ABOUT WL 2.97 M (117 IN)

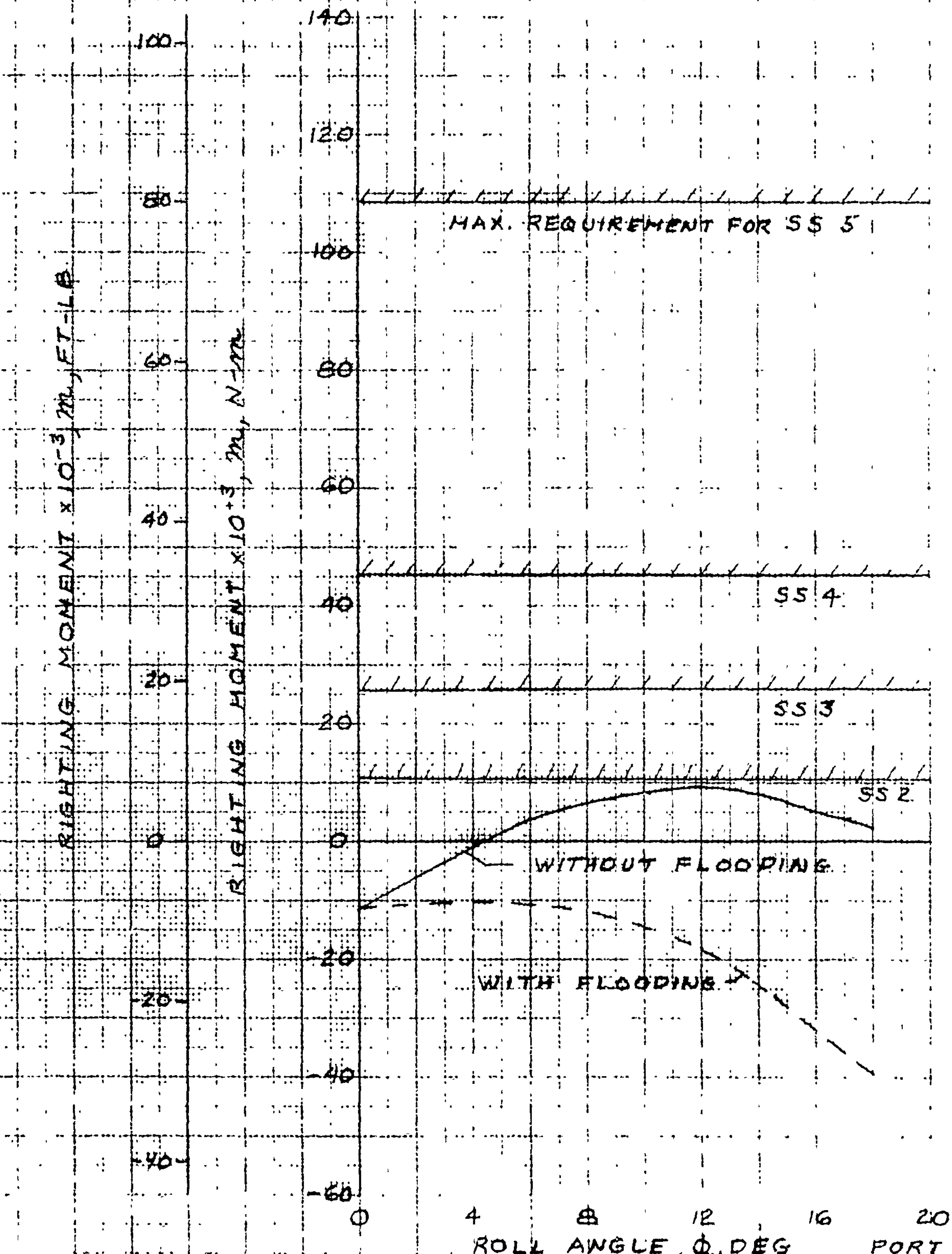


FIGURE 12 CH-53E NET RIGHTING MOMENT
ROLL ABOUT WL 3.26 M (127 IN)

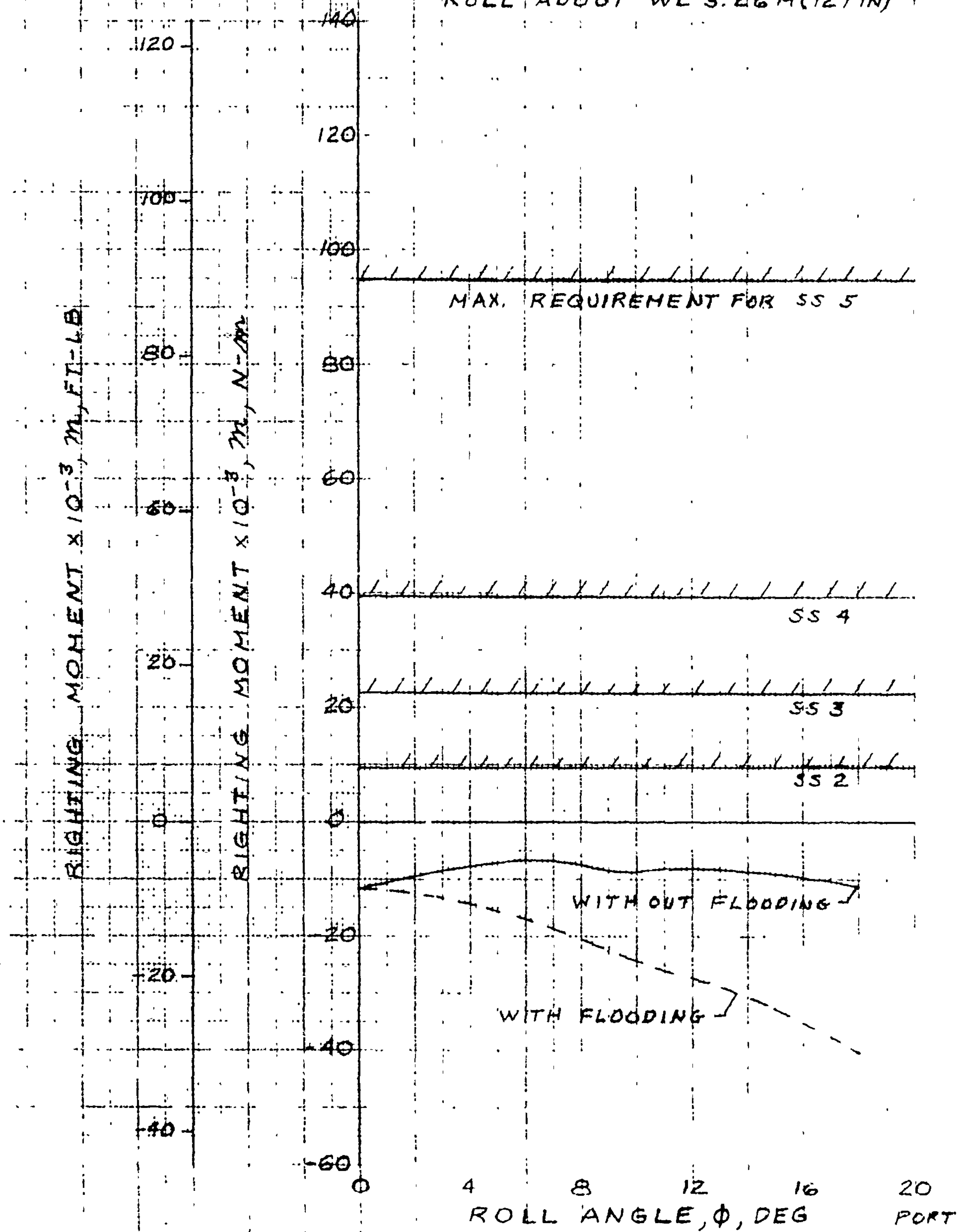


FIGURE 13 CH-53E NET RIGHTING MOMENT
ROLL ABOUT WL 3.48M (137 IN)

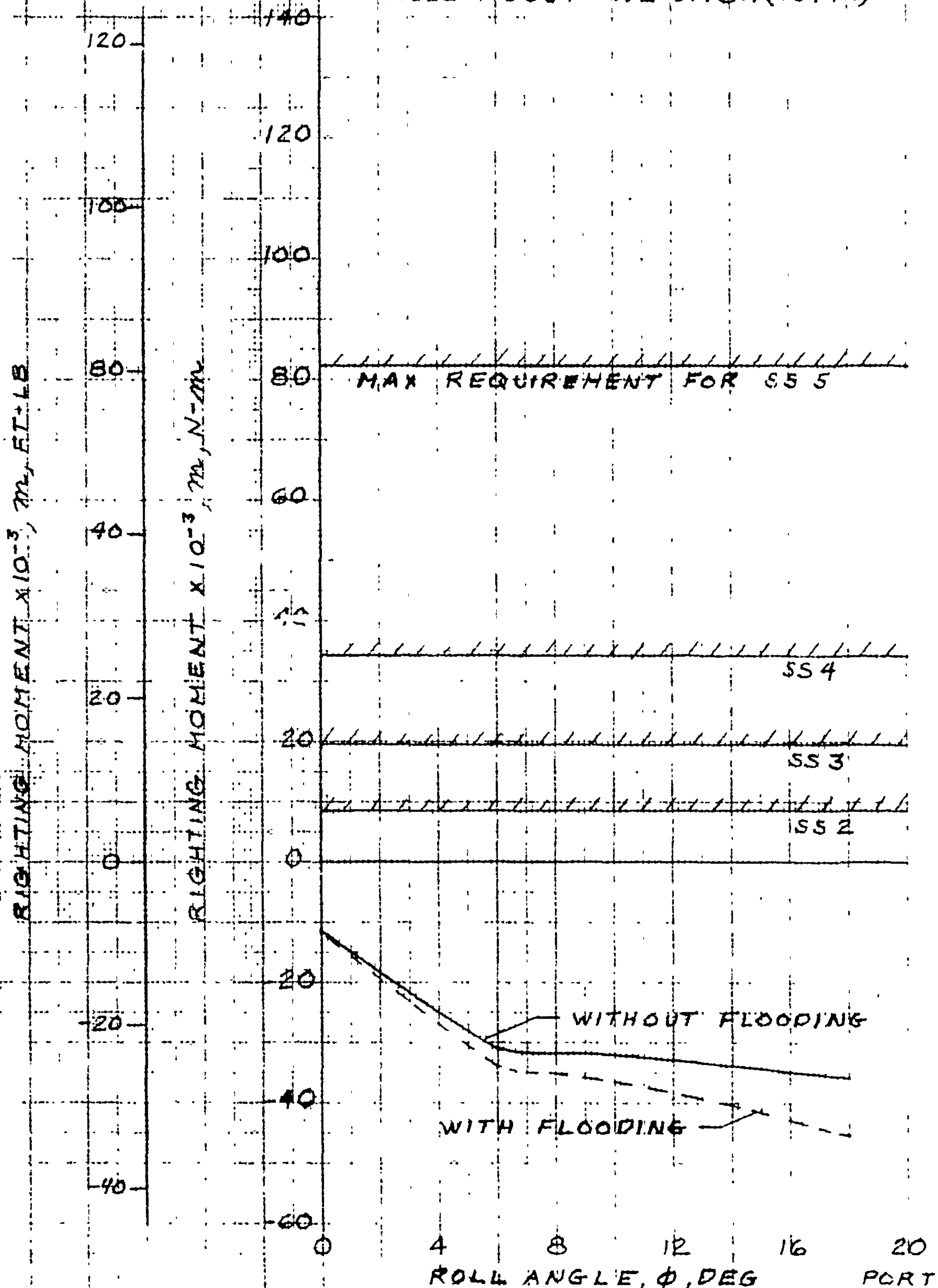


FIGURE 14. CH-53E MAXIMUM RIGHTING MOMENT VS WATERLINE OF ROLL AXIS

WITHOUT CABIN FLOODING

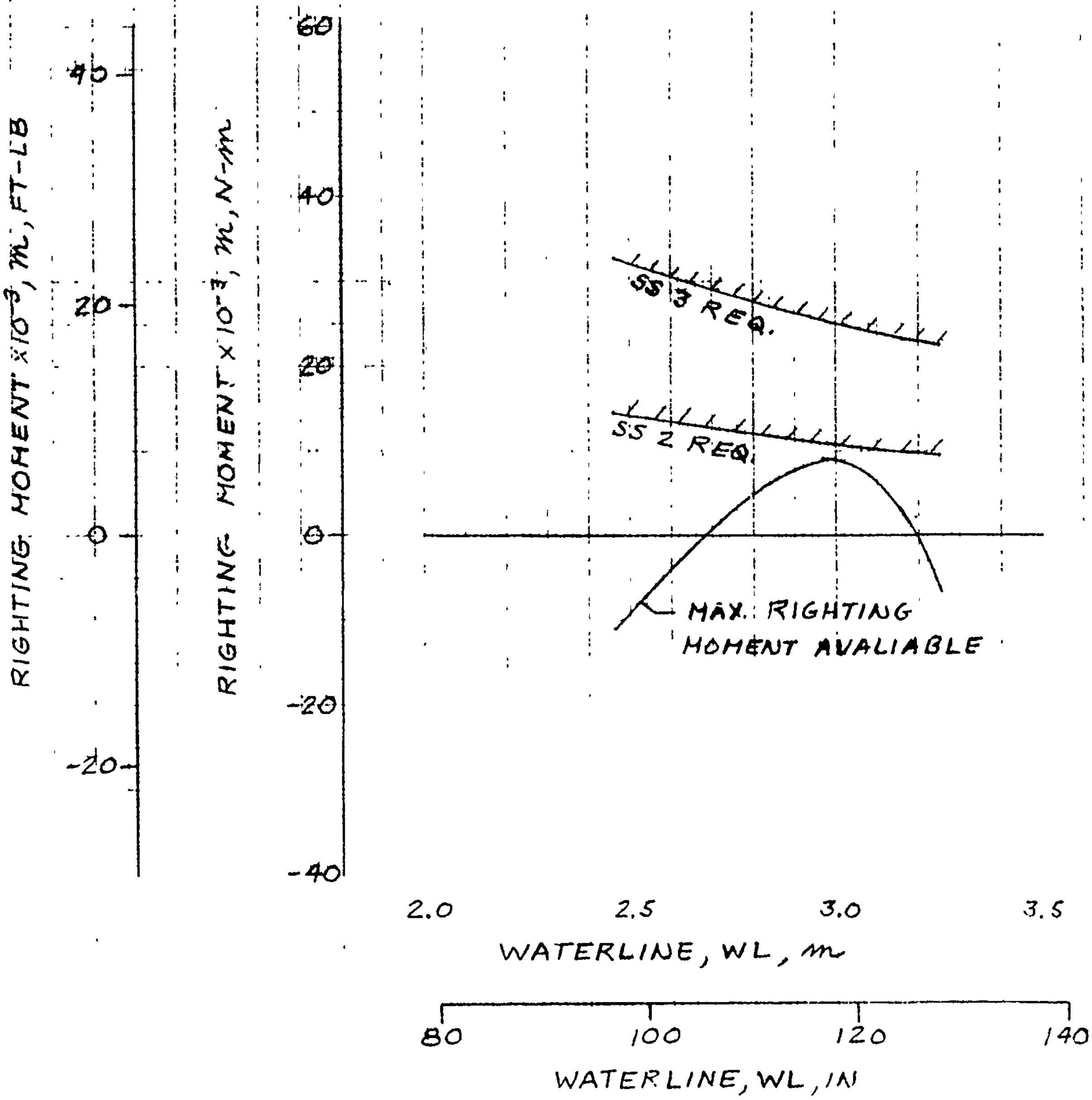


FIGURE 15 CH-53E ROTOR RPM DECAY TIME HISTORY

ENGINES OFF
FLIGHT TEST DATA A/C 159877
10% COLLECTIVE PITCH

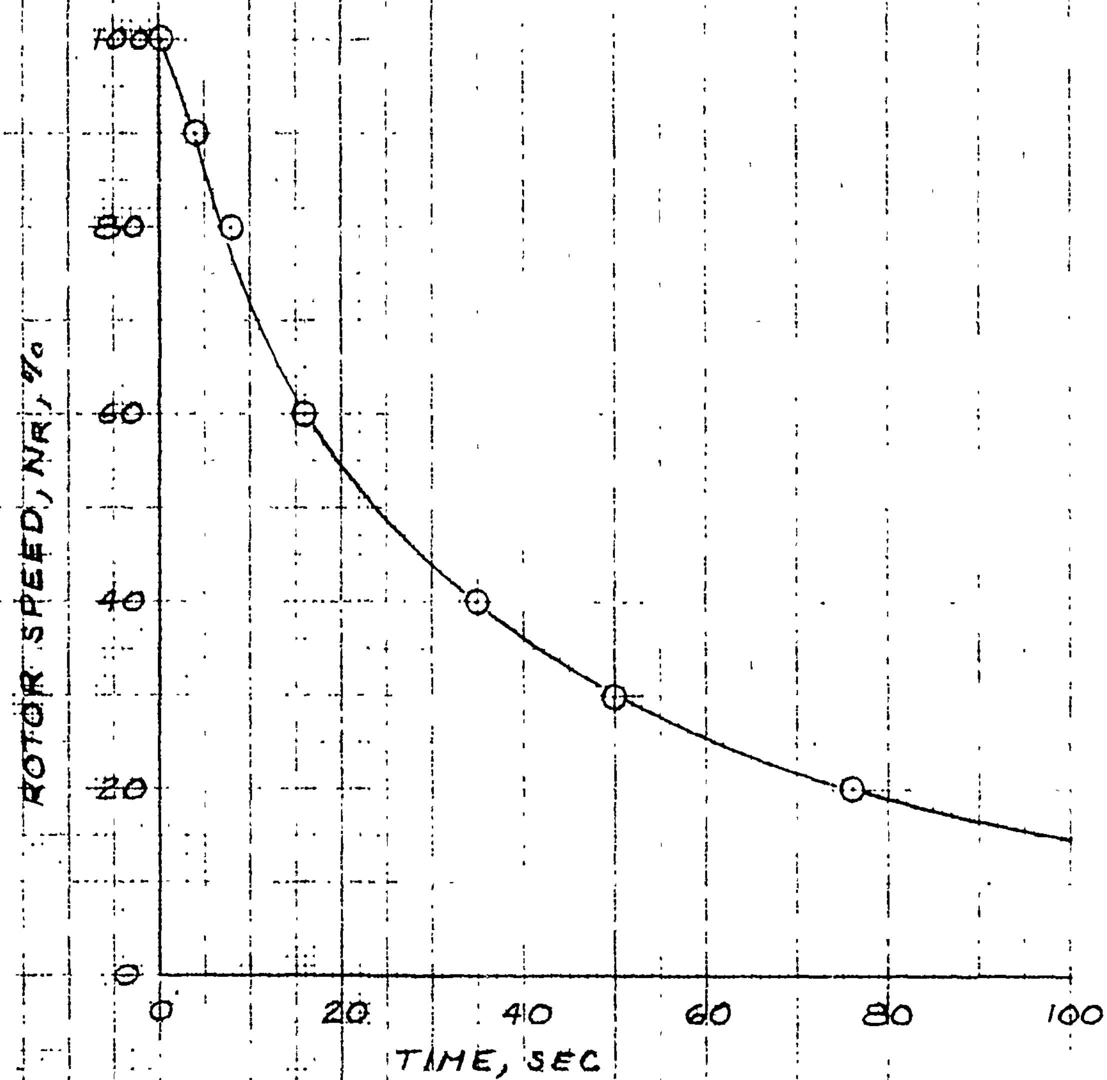
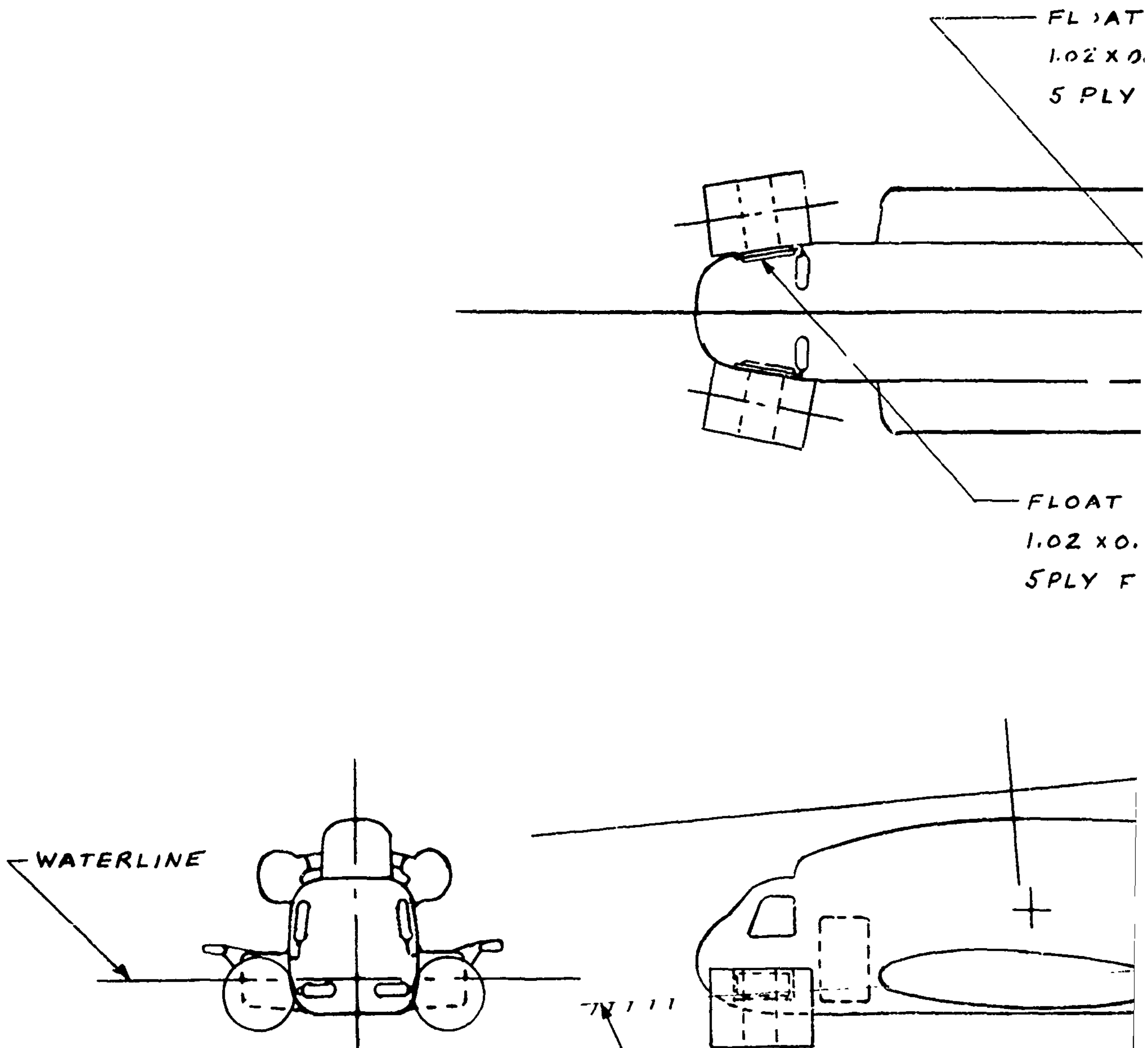


FIGURE 16 SYSTEM ONE - SEA STATE FIVE



NOTE: FLOATS SHOWN IN A VIEW LOOKING DOWN WATERLINE

FIVE

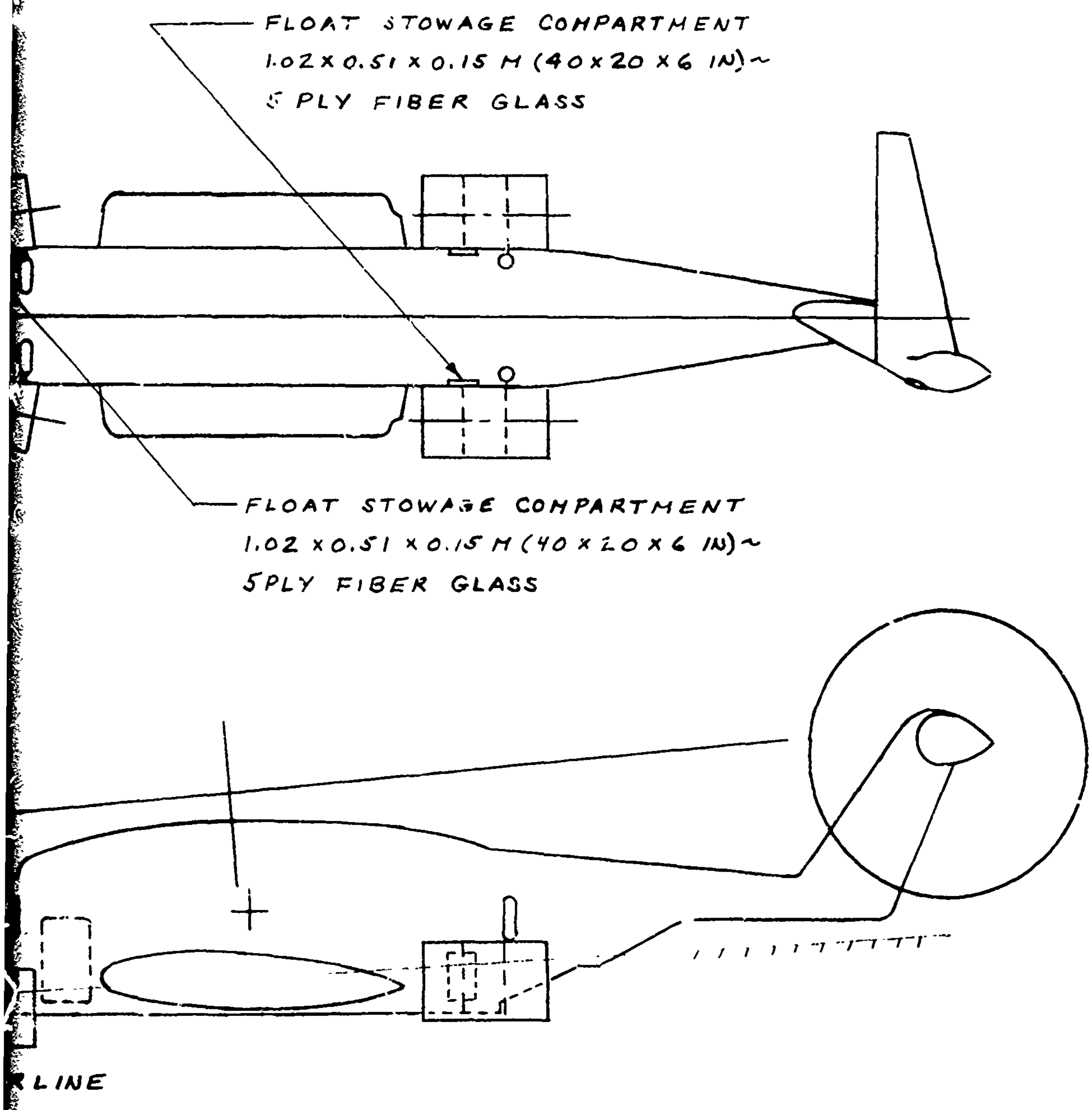
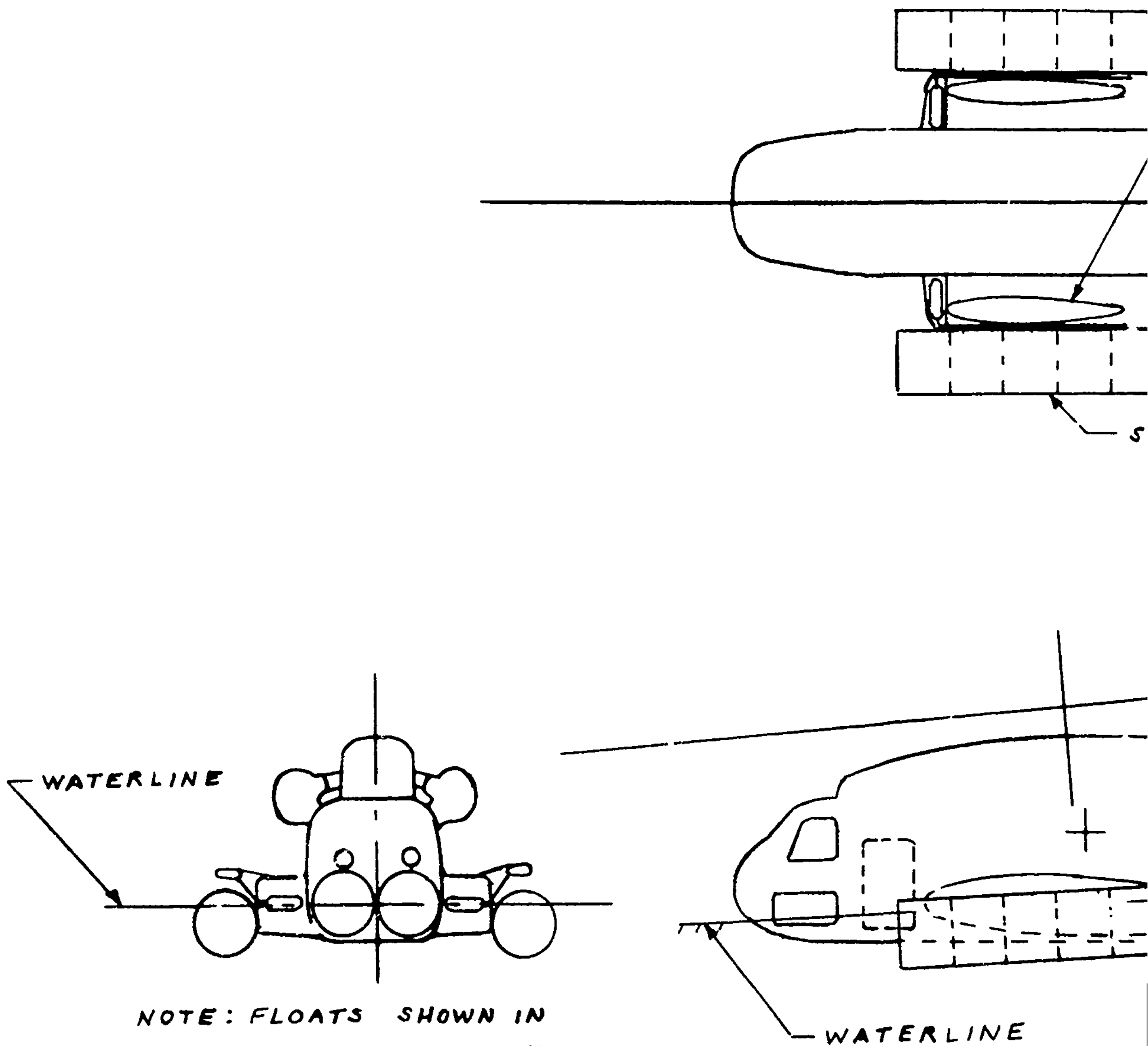
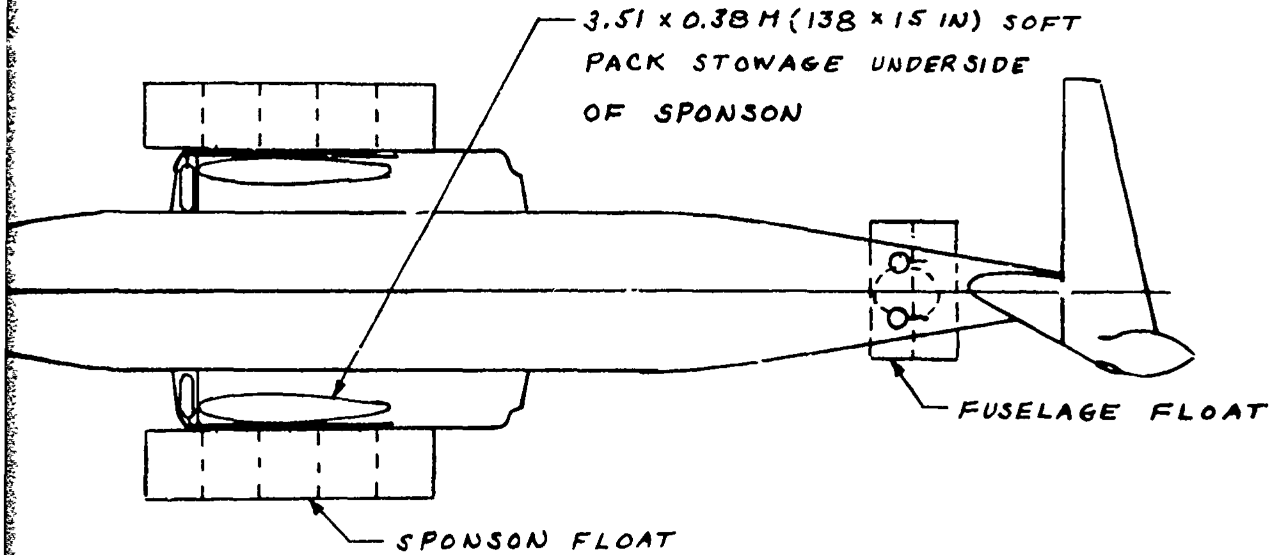

FLOAT STOWAGE COMPARTMENT
1.02 X 0.51 X 0.15 M (40 X 20 X 6 IN) ~
5 PLY FIBER GLASS
FLOAT STOWAGE COMPARTMENT
1.02 X 0.51 X 0.15 M (40 X 20 X 6 IN) ~
5 PLY FIBER GLASS
LINE

FIGURE 17 SYSTEM TWO - SEA STATE FIVE



NOTE: FLOATS SHOWN IN A VIEW LOOKING DOWN WATERLINE

TATE FIVE


3.51 x 0.38 M (138 x 15 IN) SOFT PACK STOWAGE UNDERSIDE OF SPONSON
FUSELAGE FLOAT
SPONSON FLOAT

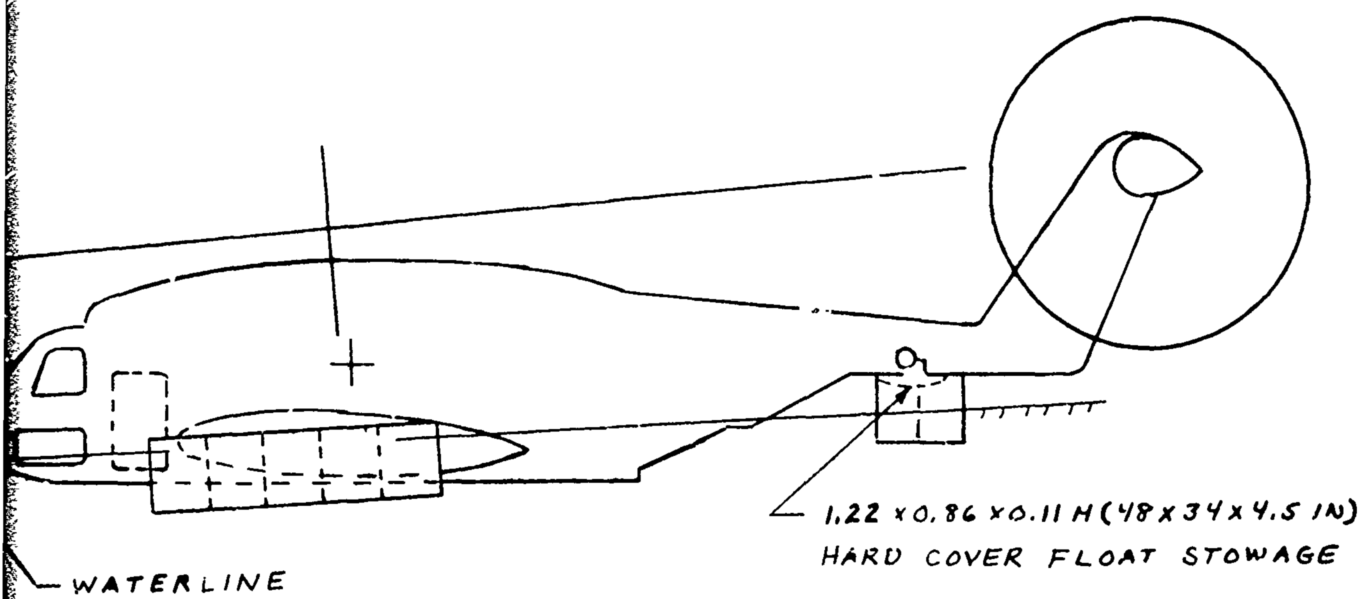
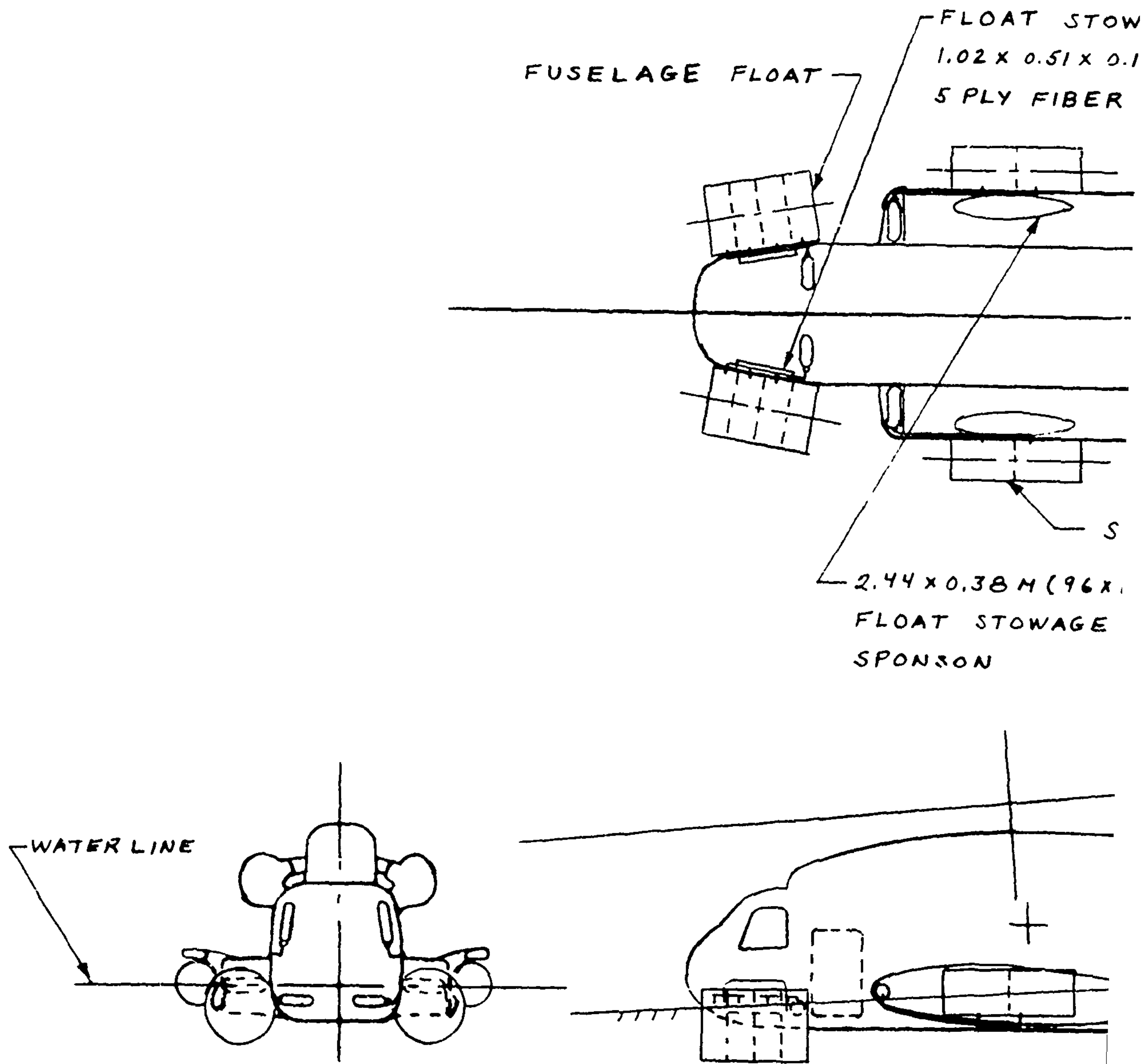

1.22 x 0.86 x 0.11 M (48 x 34 x 4.5 IN) HARD COVER FLOAT STOWAGE
WATERLINE

FIGURE 18 SYSTEM THREE - SEA STATE FIVE



NOTE: FLOATS SHOWN IN A
VIEW LOOKING DOWN WATERLINE

TATE FIVE

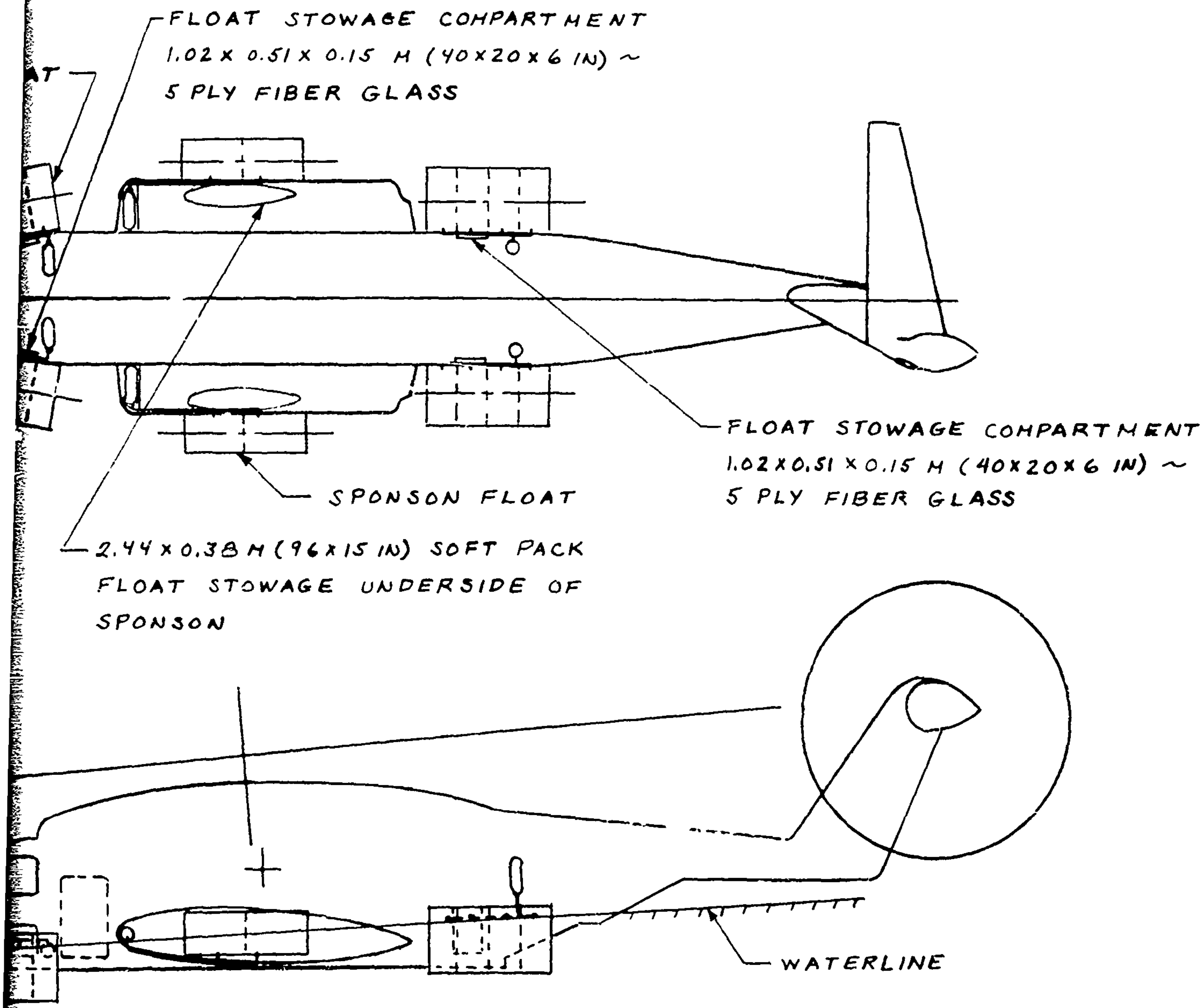
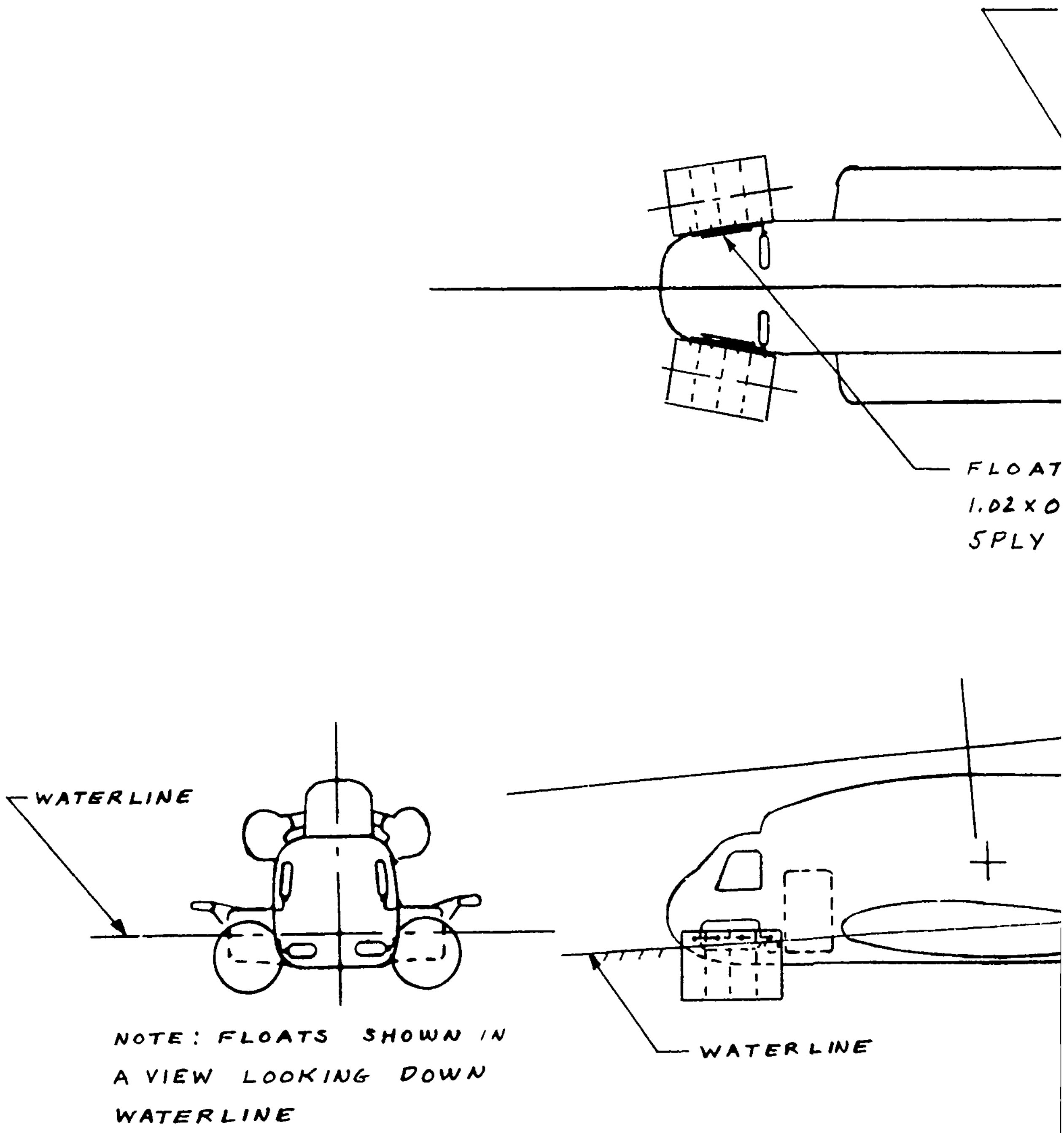

FLOAT STOWAGE COMPARTMENT
1.02 x 0.51 x 0.15 M (40 x 20 x 6 IN) ~
5 PLY FIBER GLASS
FLOAT STOWAGE COMPARTMENT
1.02 x 0.51 x 0.15 M (40 x 20 x 6 IN) ~
5 PLY FIBER GLASS
SPONSON FLOAT
2.44 x 0.38 M (96 x 15 IN) SOFT PACK
FLOAT STOWAGE UNDERSIDE OF
SPONSON
WATERLINE

FIGURE 19 SYSTEM FOUR - SEA STATE FOUR



STATE FOUR

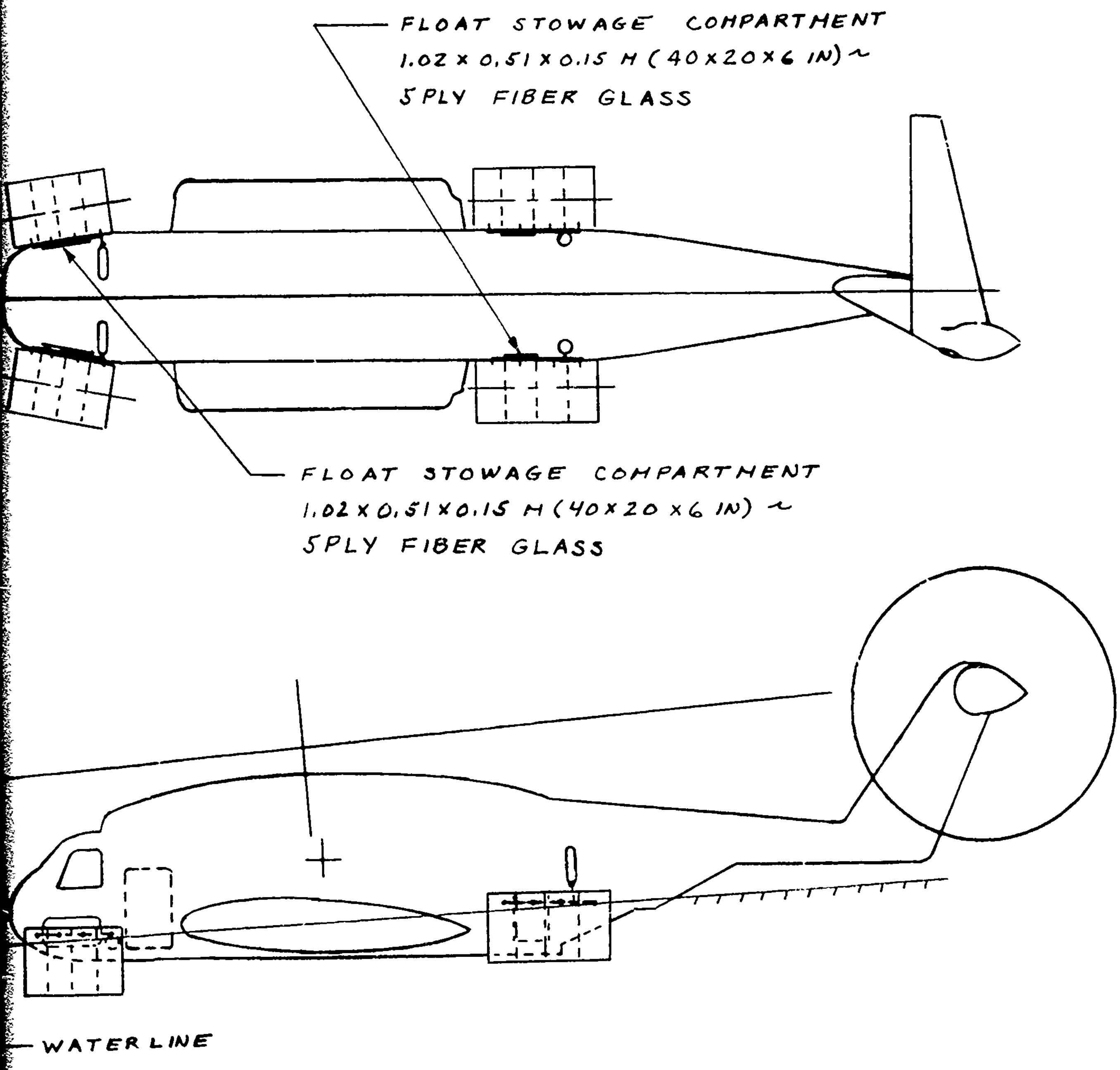
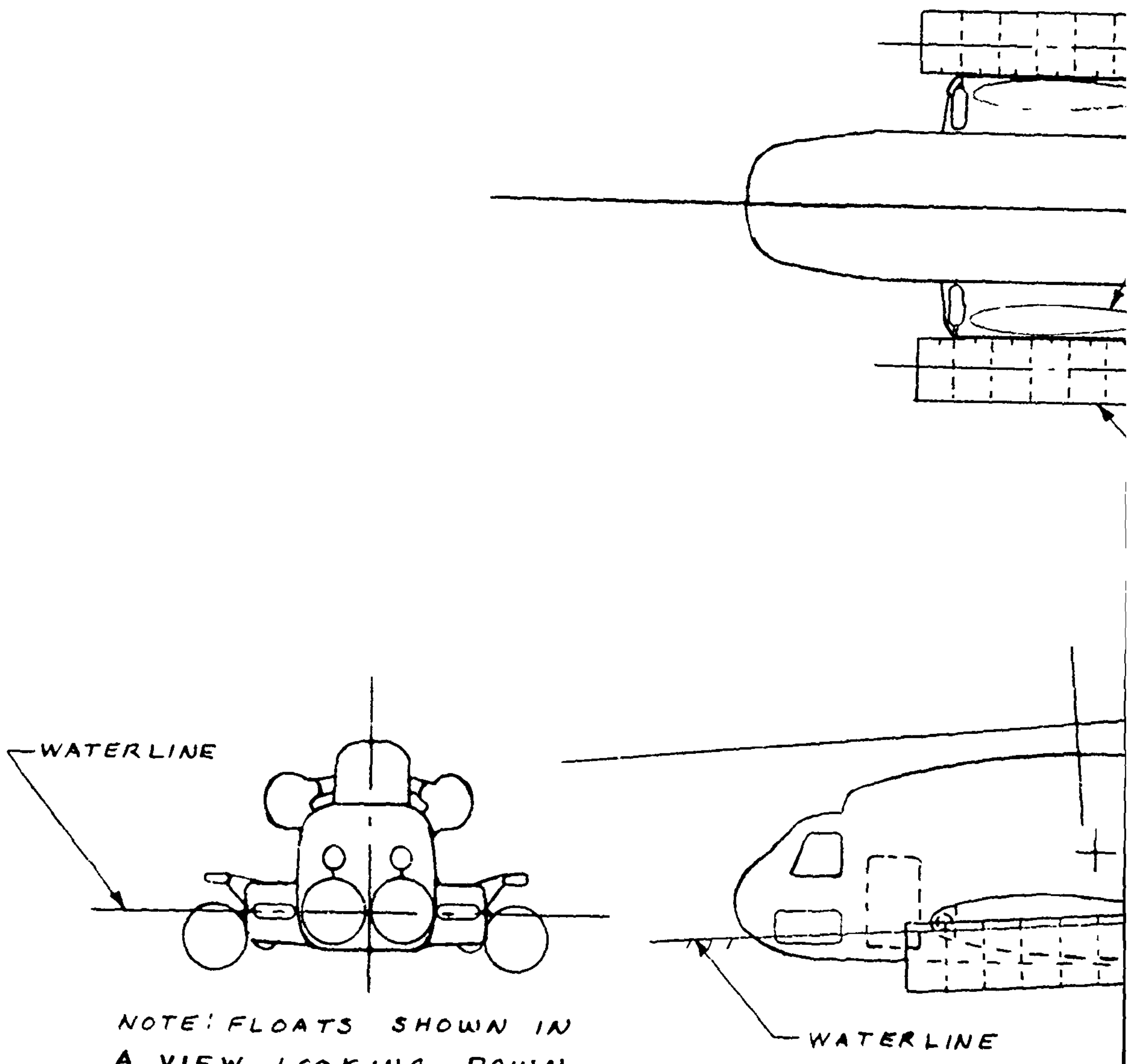

FLOAT STOWAGE COMPARTMENT
1.02 x 0.51 x 0.15 M (40 x 20 x 6 IN) ~
5PLY FIBER GLASS
FLOAT STOWAGE COMPARTMENT
1.02 x 0.51 x 0.15 M (40 x 20 x 6 IN) ~
5PLY FIBER GLASS
WATERLINE

FIGURE 20 SYSTEM FIVE - SEA STATE FOUR



NOTE: FLOATS SHOWN IN A VIEW LOOKING DOWN WATERLINE

STATE FOUR

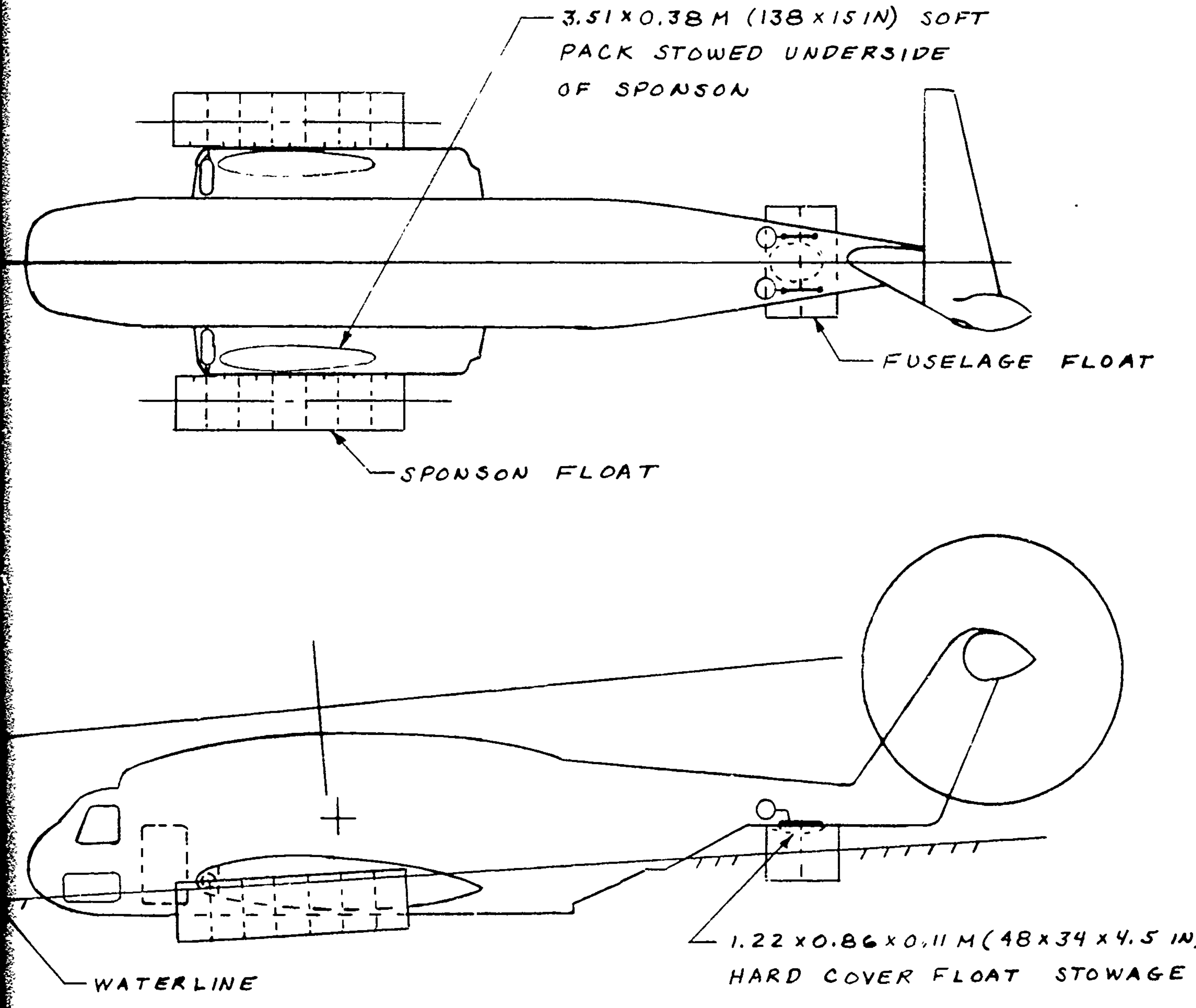
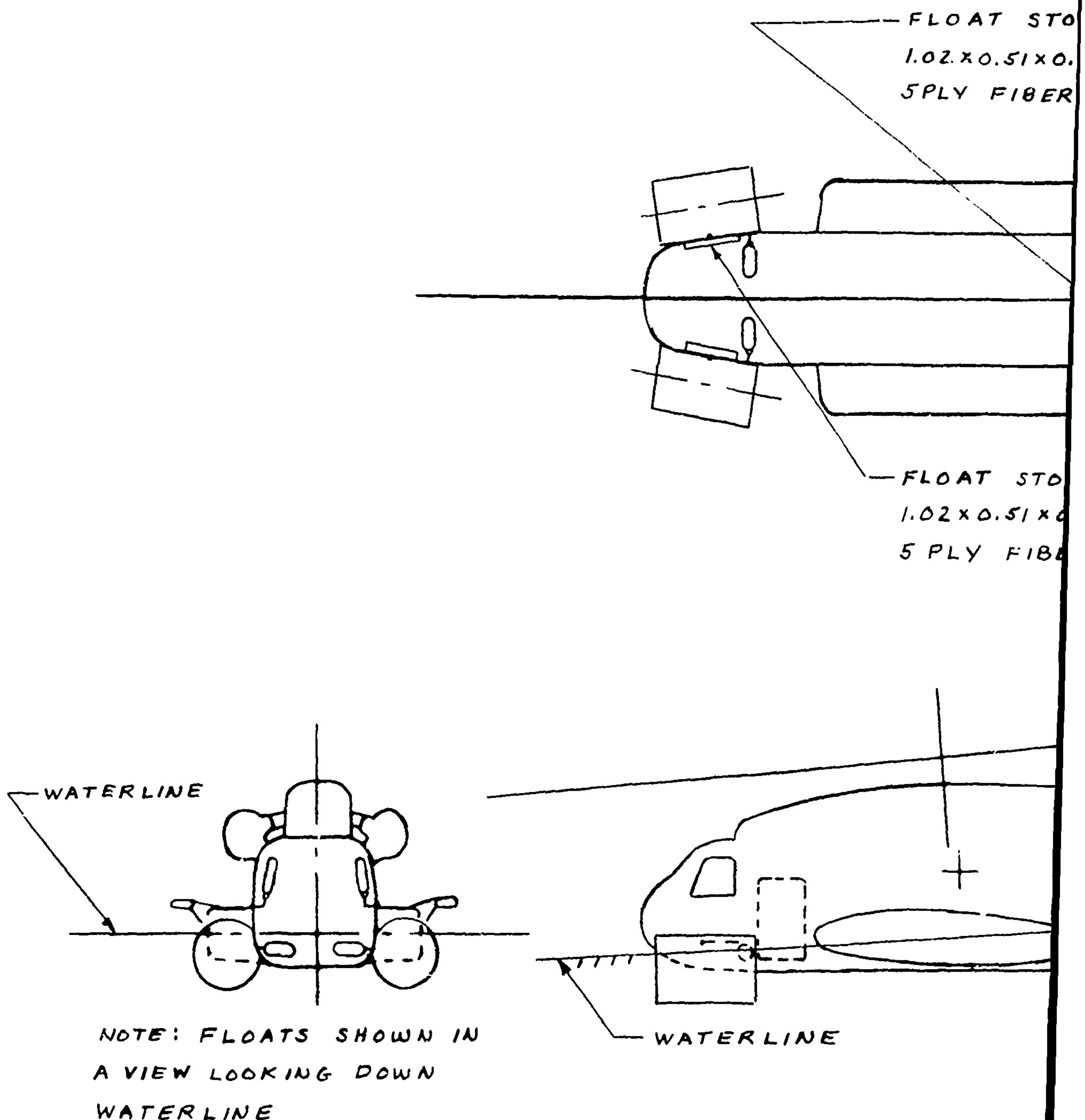
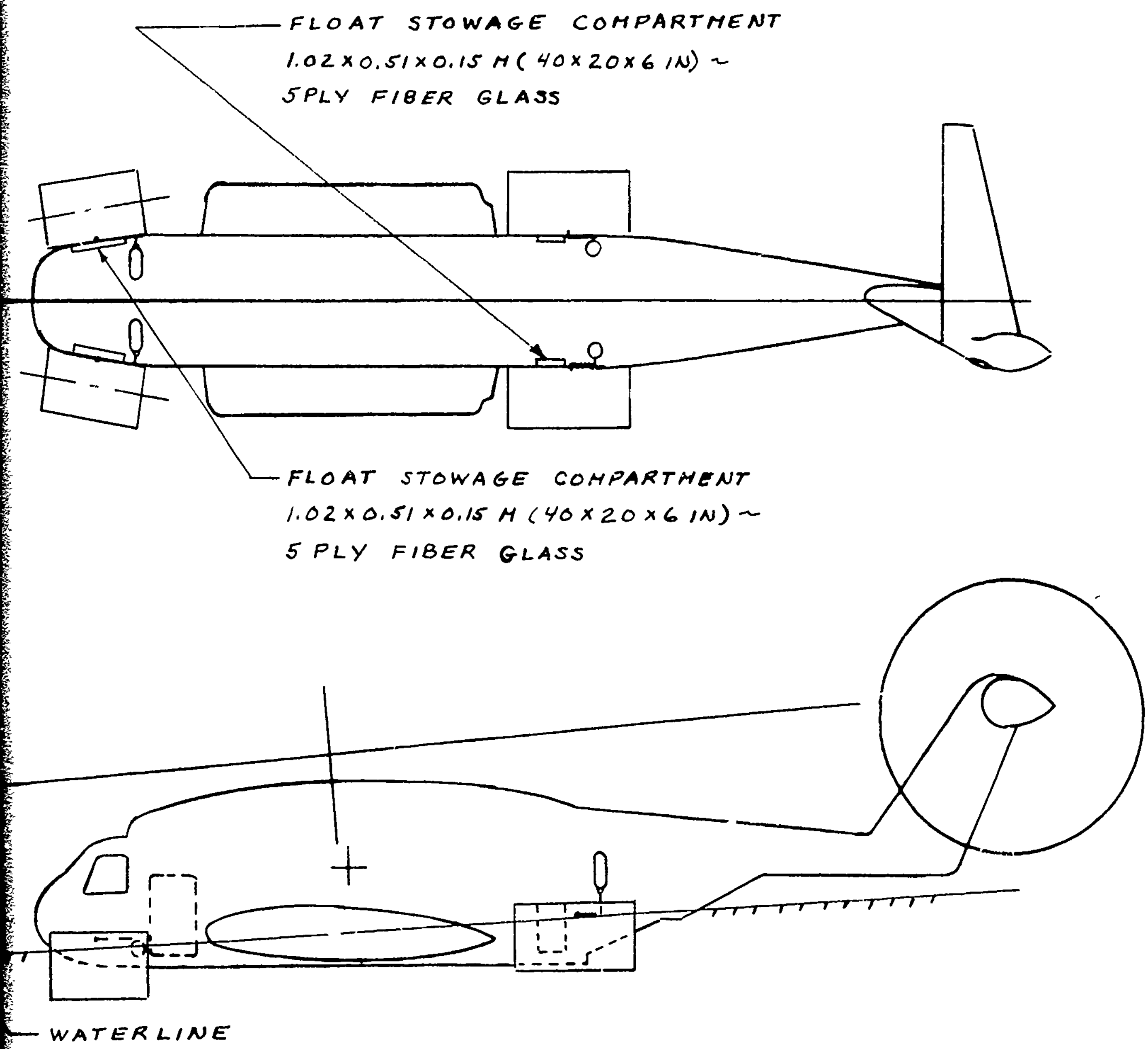

3.51 x 0.38 M (138 x 15 IN) SOFT PACK STOWED UNDERSIDE OF SPONSON
FUSELAGE FLOAT
SPONSON FLOAT
WATERLINE
1.22 x 0.86 x 0.11 M (48 x 34 x 4.5 IN) HARD COVER FLOAT STOWAGE

FIGURE 21 SYSTEM SIX – SEA STATE TWO



A STATE TWO


FLOAT STOWAGE COMPARTMENT
1.02 X 0.51 X 0.15 M (40 X 20 X 6 IN) ~
5 PLY FIBER GLASS
FLOAT STOWAGE COMPARTMENT
1.02 X 0.51 X 0.15 M (40 X 20 X 6 IN) ~
5 PLY FIBER GLASS
WATERLINE

UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

FIGURE 22 SYSTEM ONE HYDRODYNAMIC CAPABILITY WITH CABIN FLOODING

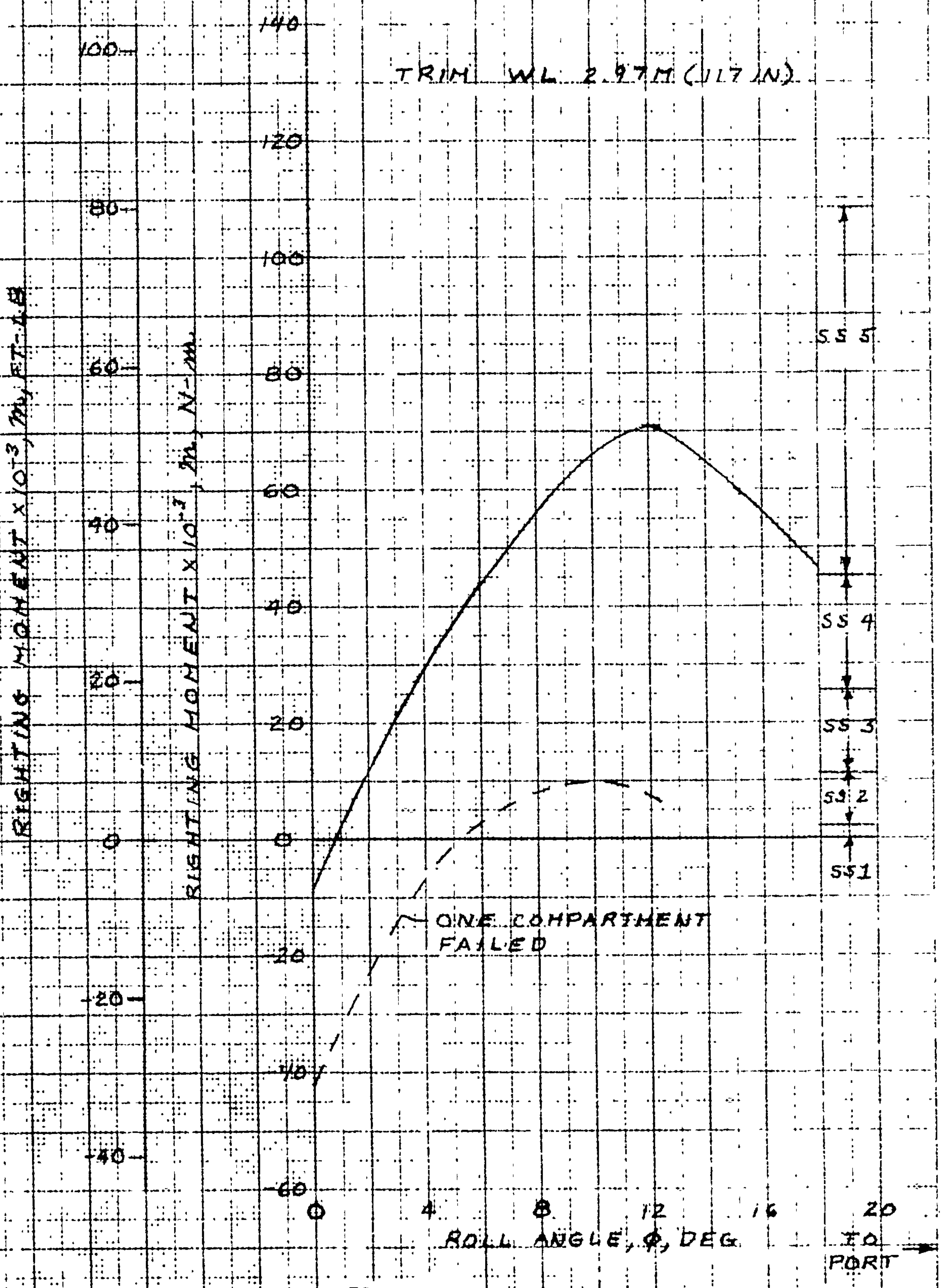


FIGURE 23 SYSTEM TWO HYDRODYNAMIC CAPABILITY WITH CABIN FLOODING

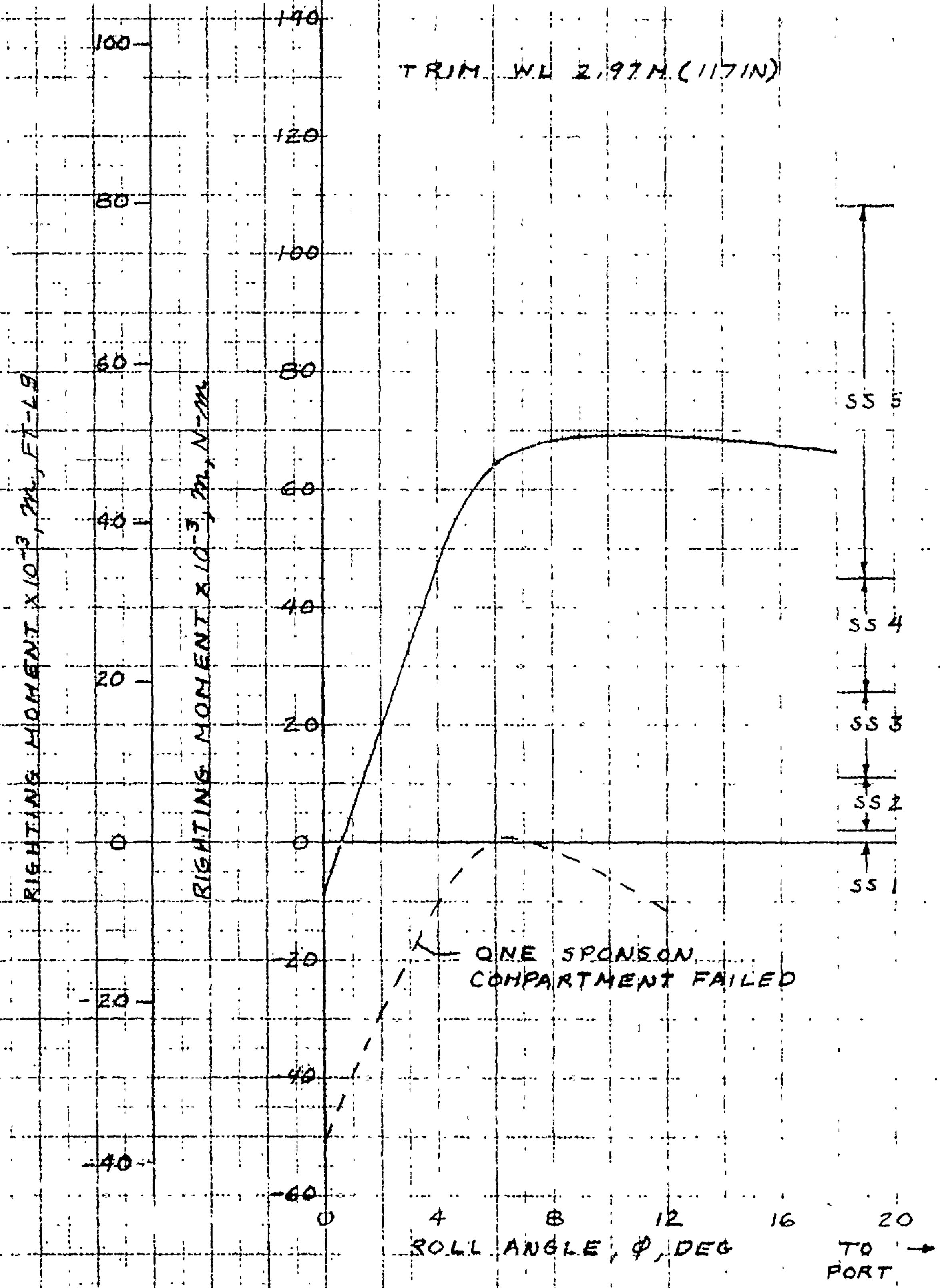


FIGURE 24 SYSTEM THREE HYDRODYNAMIC CAPABILITY WITH CABIN FLOODING

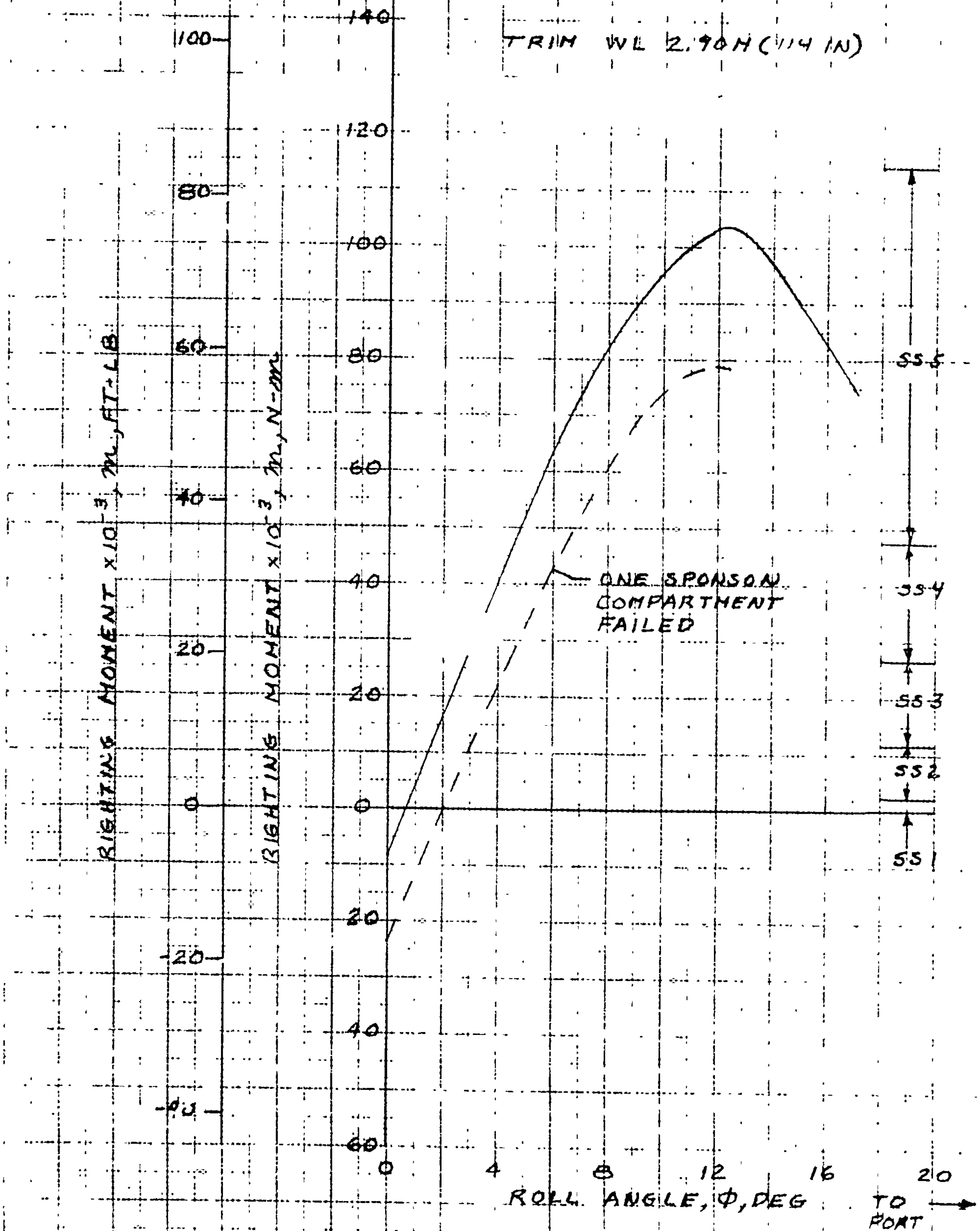


FIGURE 26 SYSTEM FOUR HYDRODYNAMIC CAPABILITY WITH CABIN FLOODING

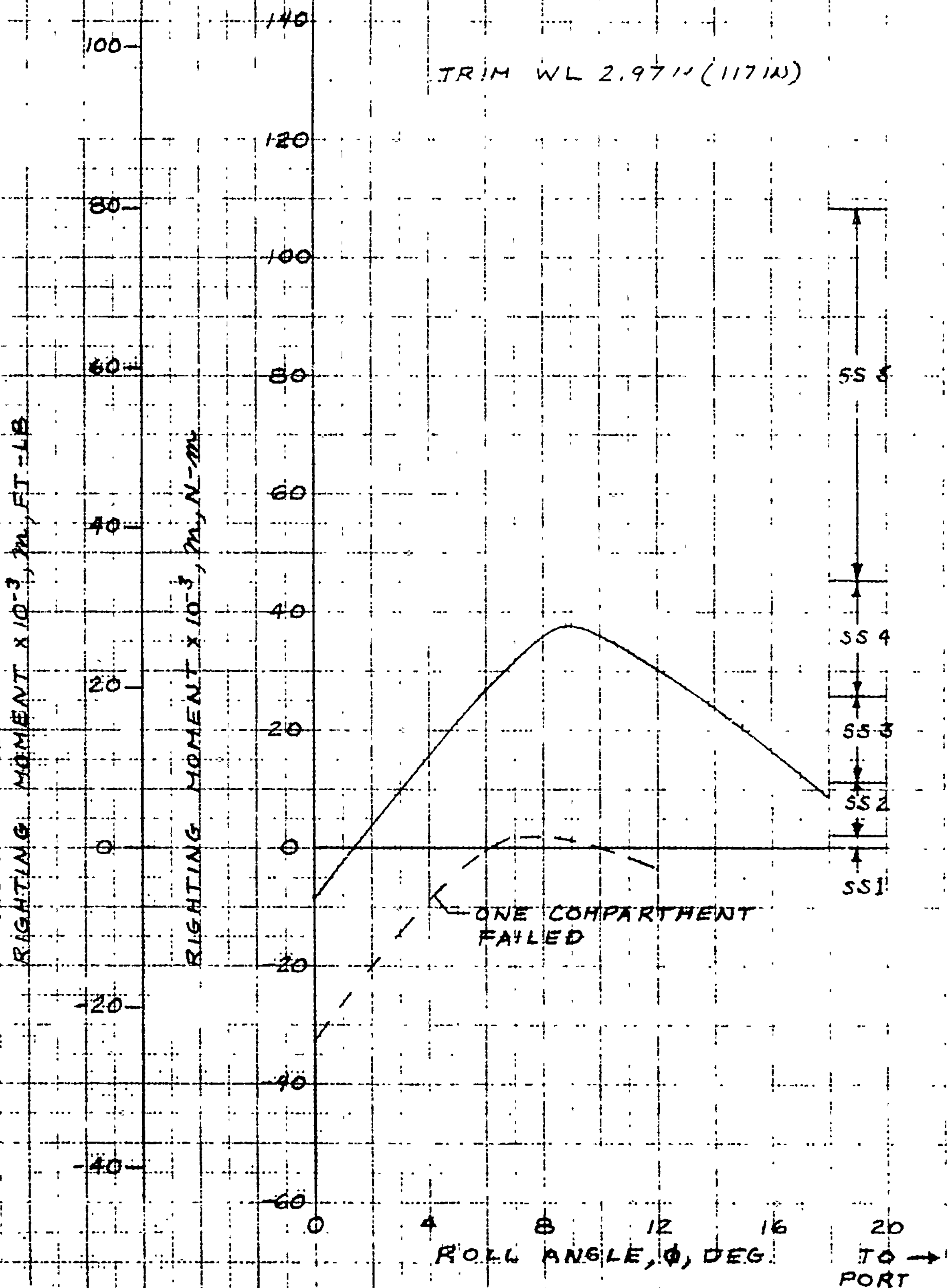


FIGURE 26 SYSTEM FIVE HYDRODYNAMIC CAPABILITY WITH CABIN FLOODING

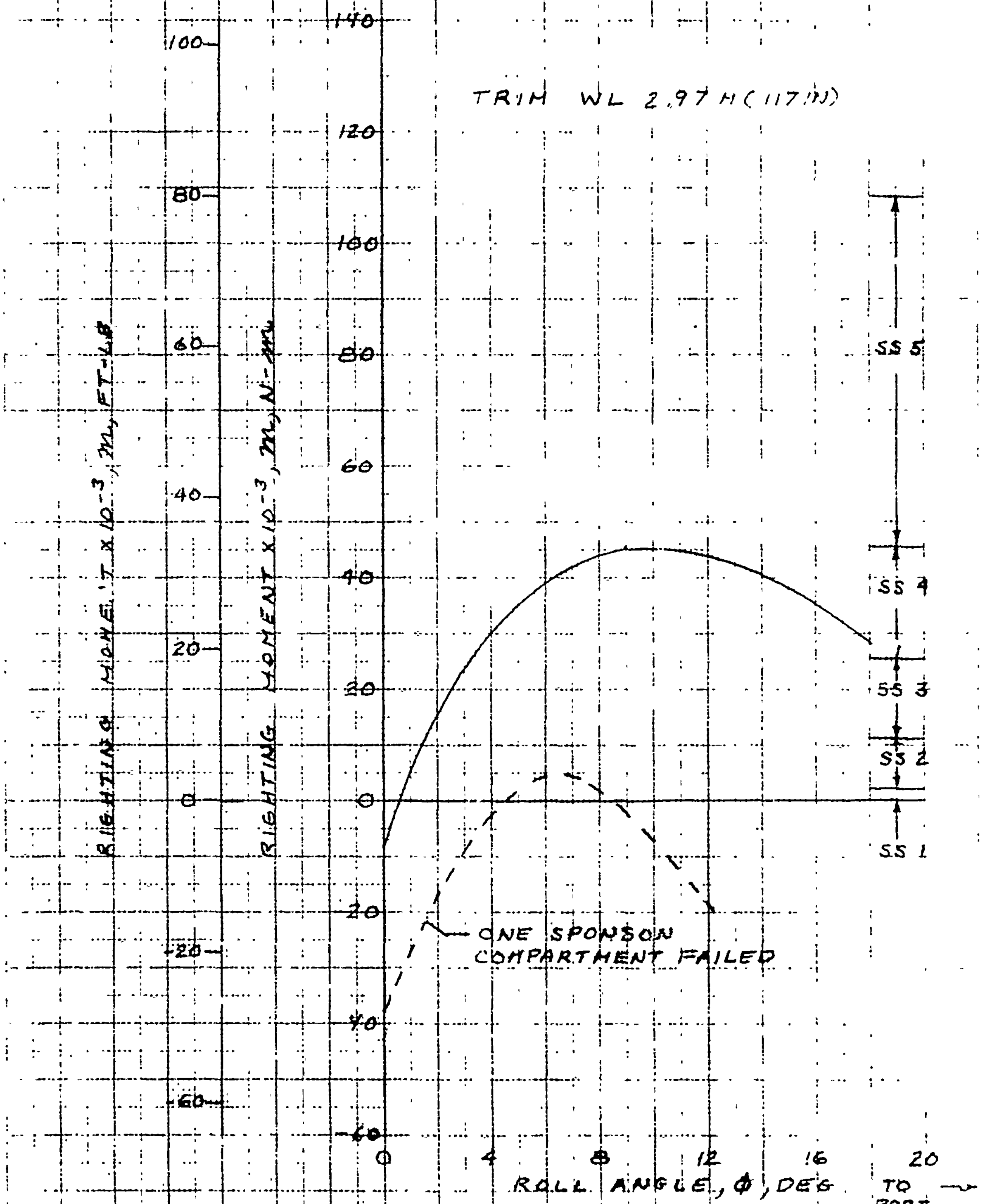


FIGURE 27 SYSTEM SIX HYDRODYNAMIC CAPABILITY WITH CABIN FLOODING

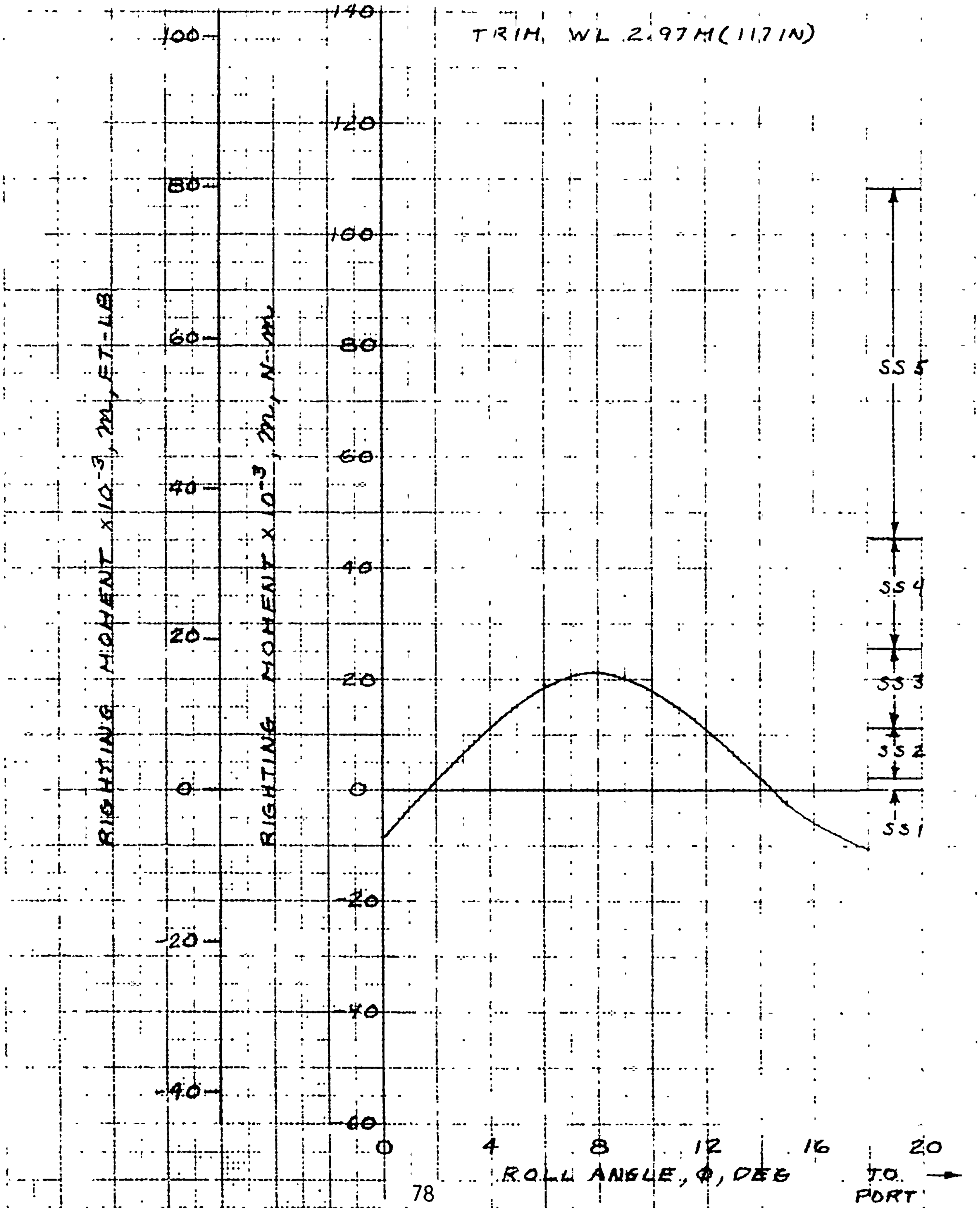
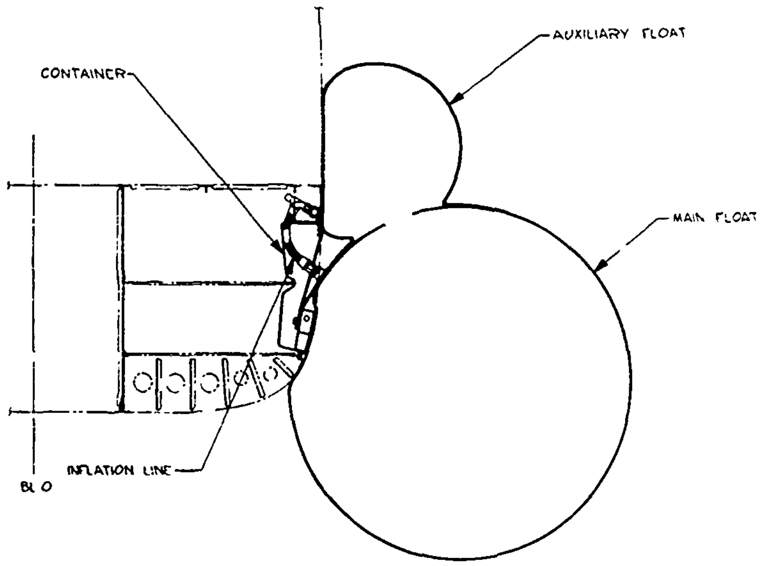
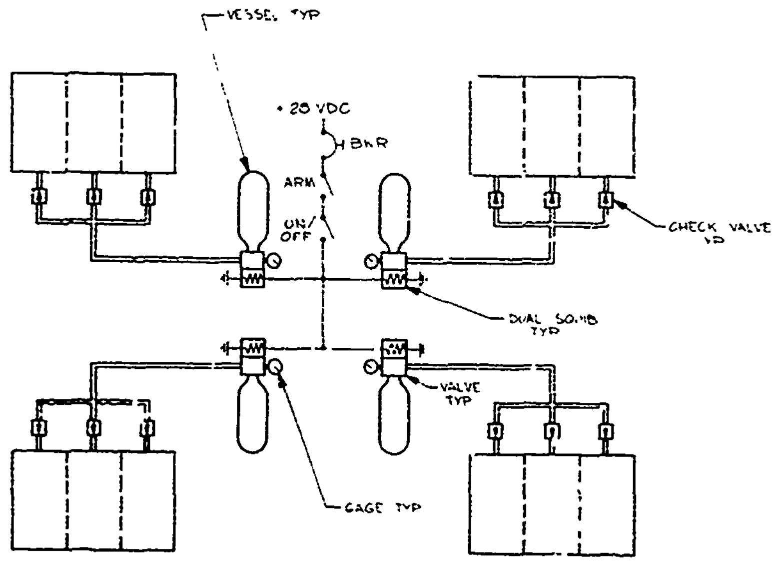


FIGURE 28 SYSTEM ONE (SEA STATE 5) DETAIL THREE-VIEW DRAWING

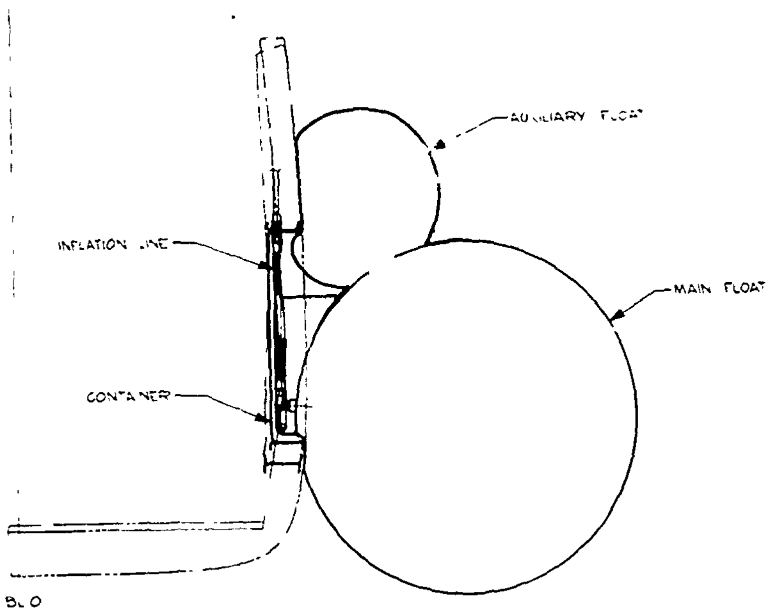


SECTION A-A
VIEW LOOKING AFT, LH SIDE
SCALE 1/10

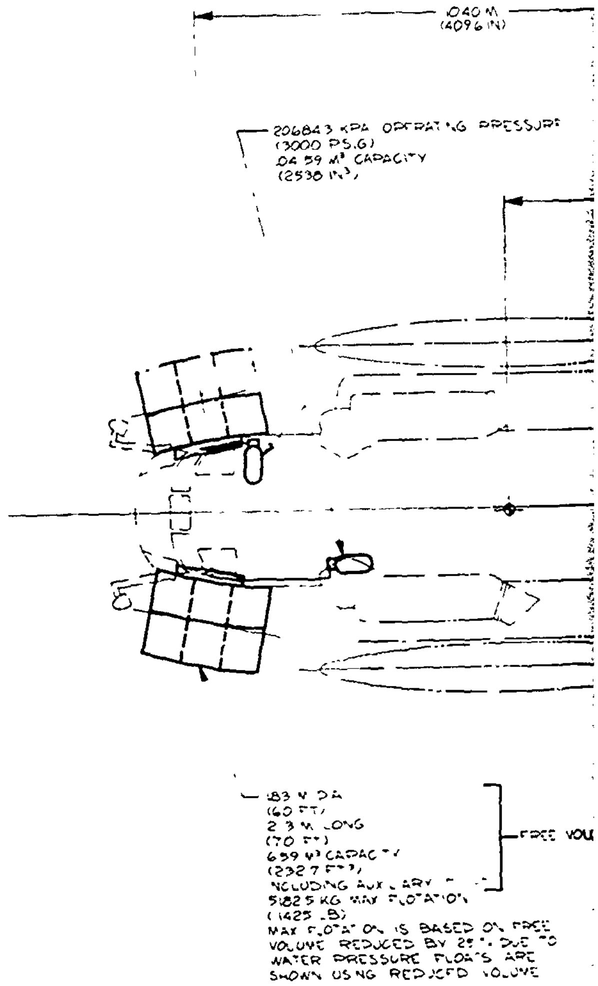


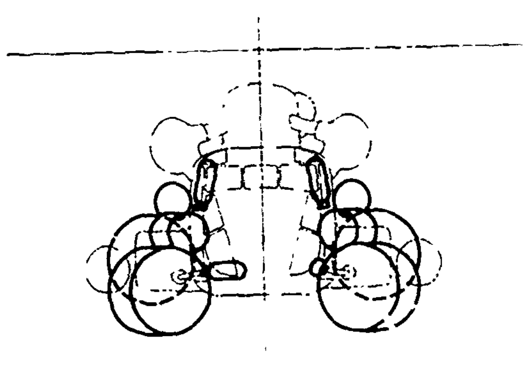
SYSTEM SCHEMATIC

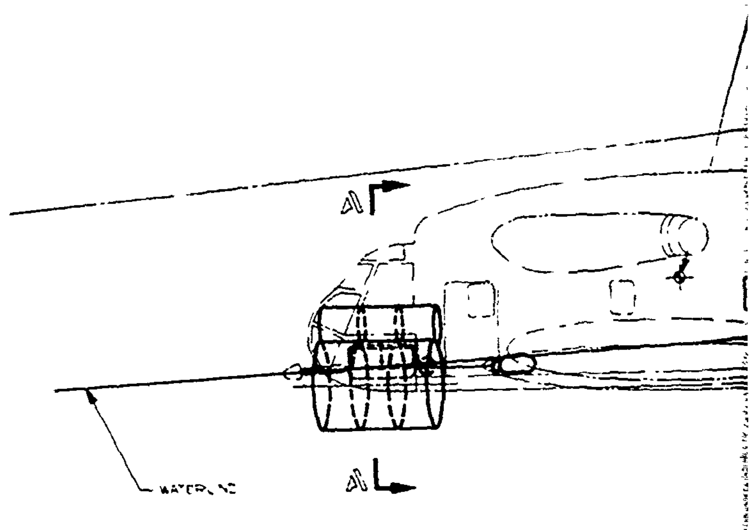
ATE 5)
W DRAWING



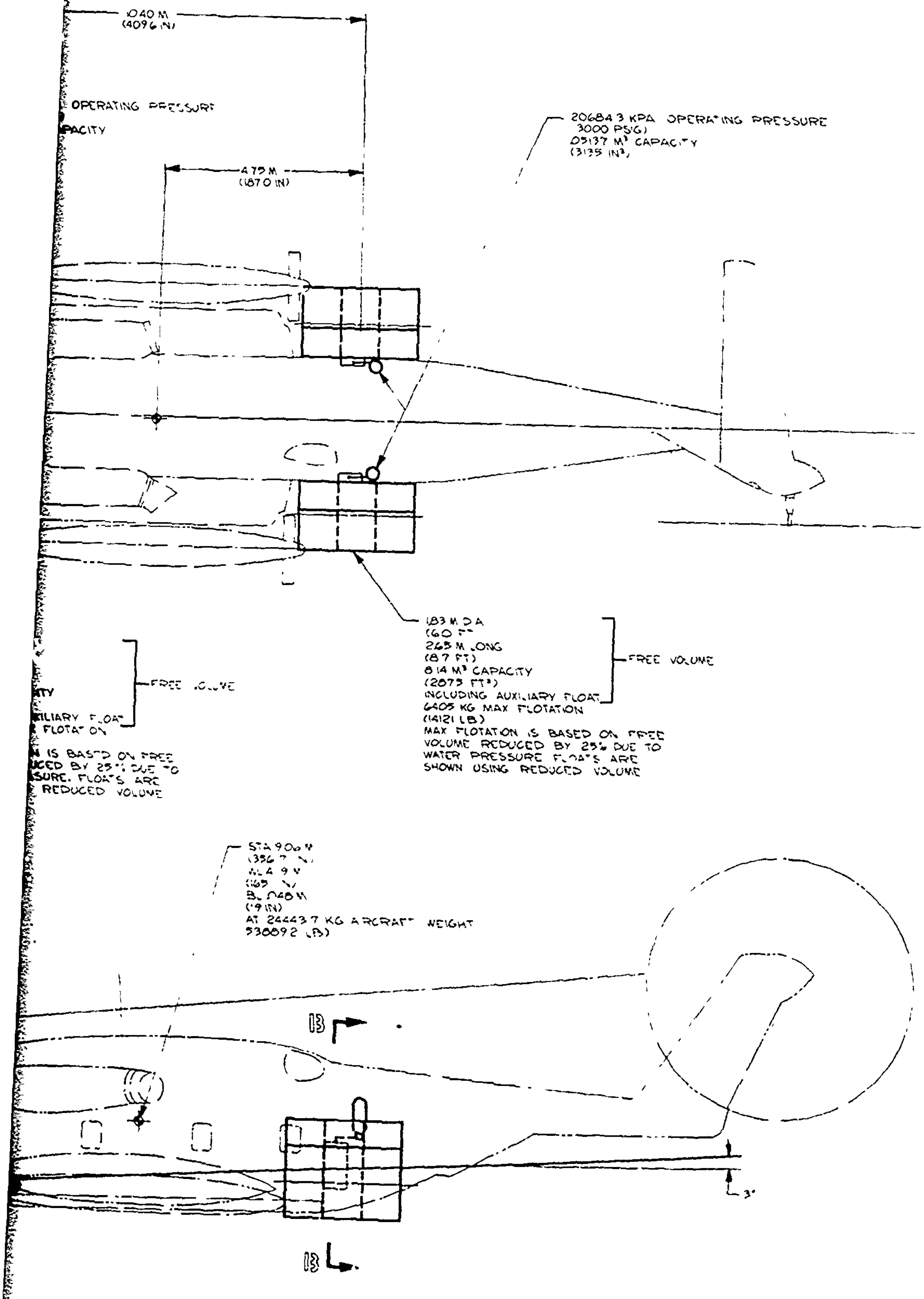
SECTION B - B
VIEW LOOKING AFT, LH SIDE
SCALE 1/10







12



CONTRACT NUMBER N62269-80-C-0210

SIKORSKY AIRCRAFT — STRATFORD, CONNECTICUT

FLOTATION SYSTEM
SEA STATE 5
CH-53E

FSCM NO 78286 — DRAWING NUMBER S65-1

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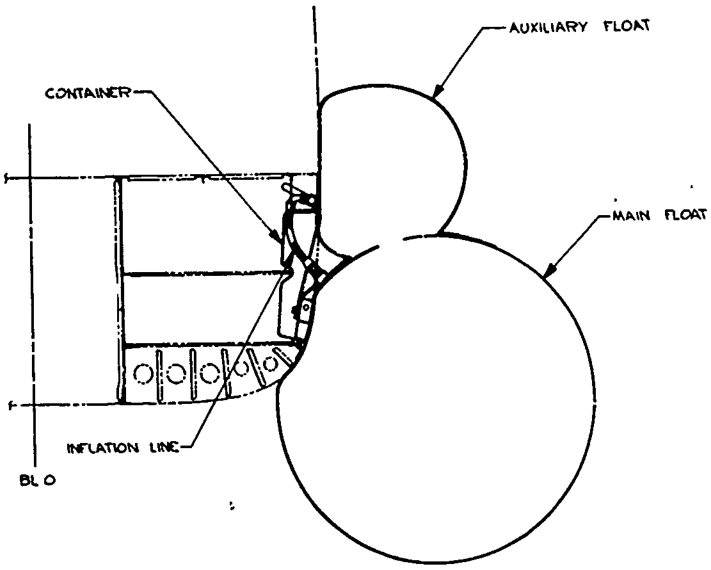
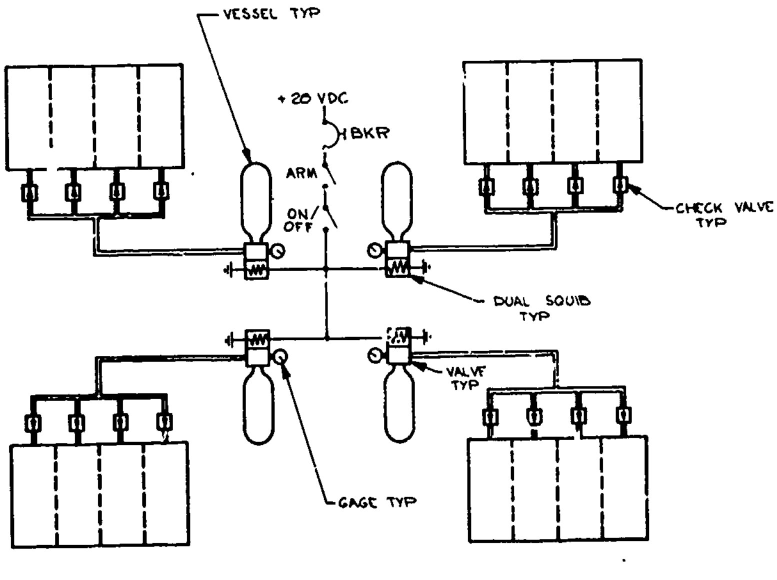
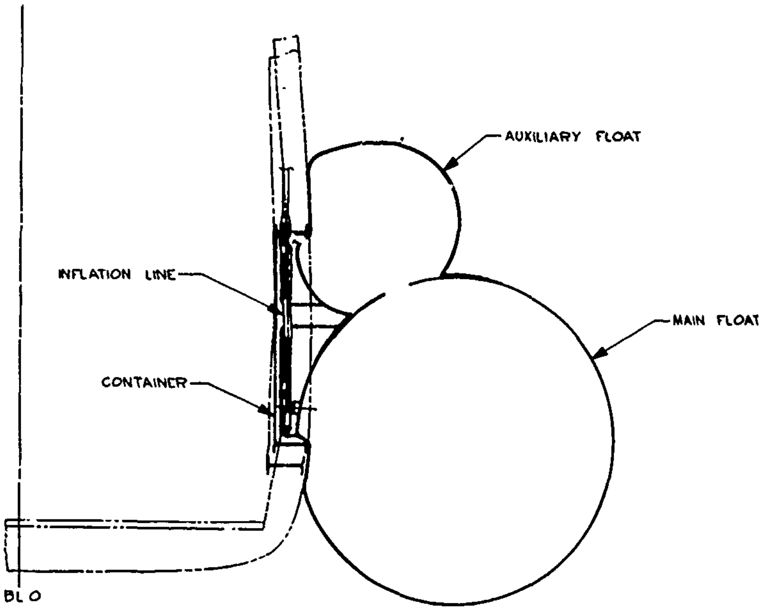
FIGURE 29 SYSTEM FOUR (SEA STATE 4) DETAIL THREE-VIEW DRAWING



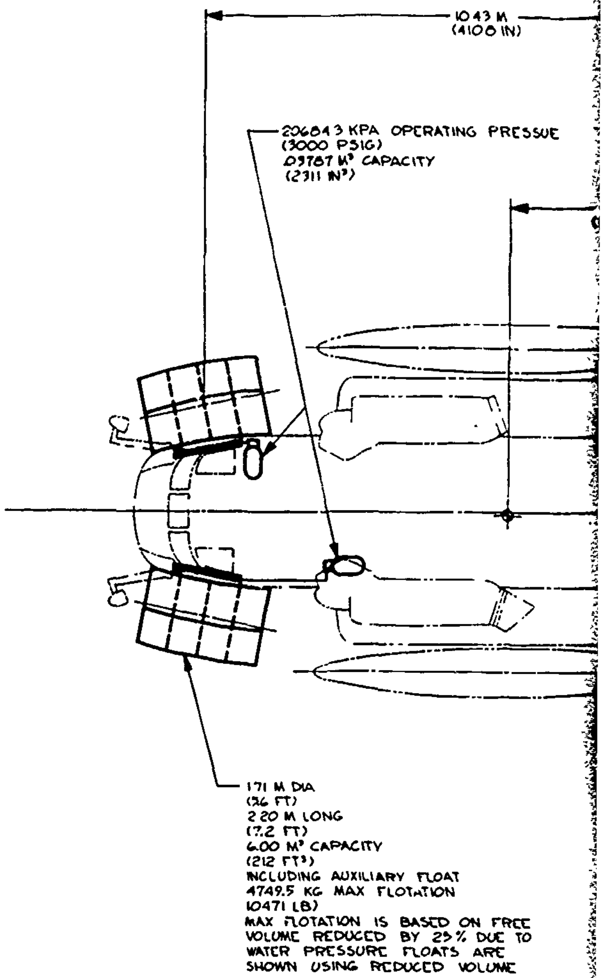
SECTION A-A
VIEW LOOKING AFT, LH SIDE
SCALE 1/10

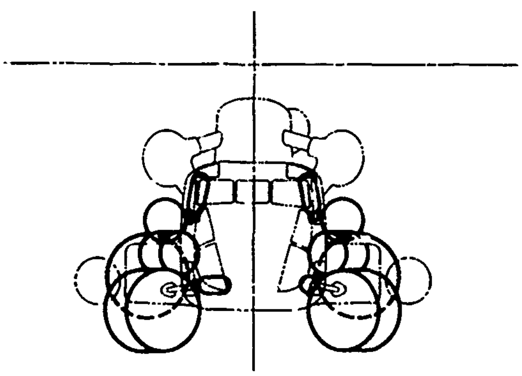


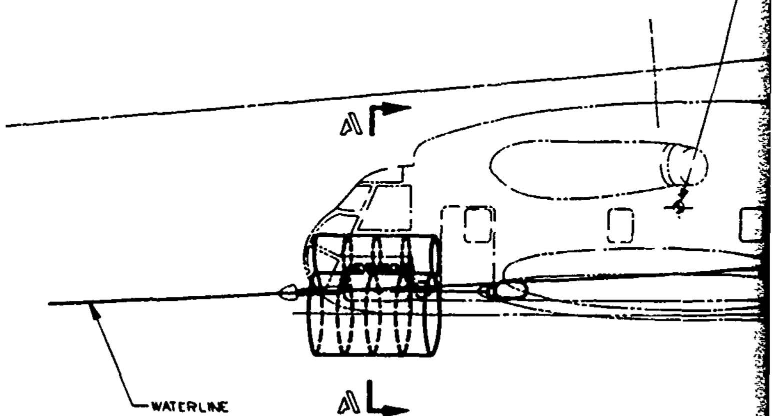
SYSTEM SCHEMATIC

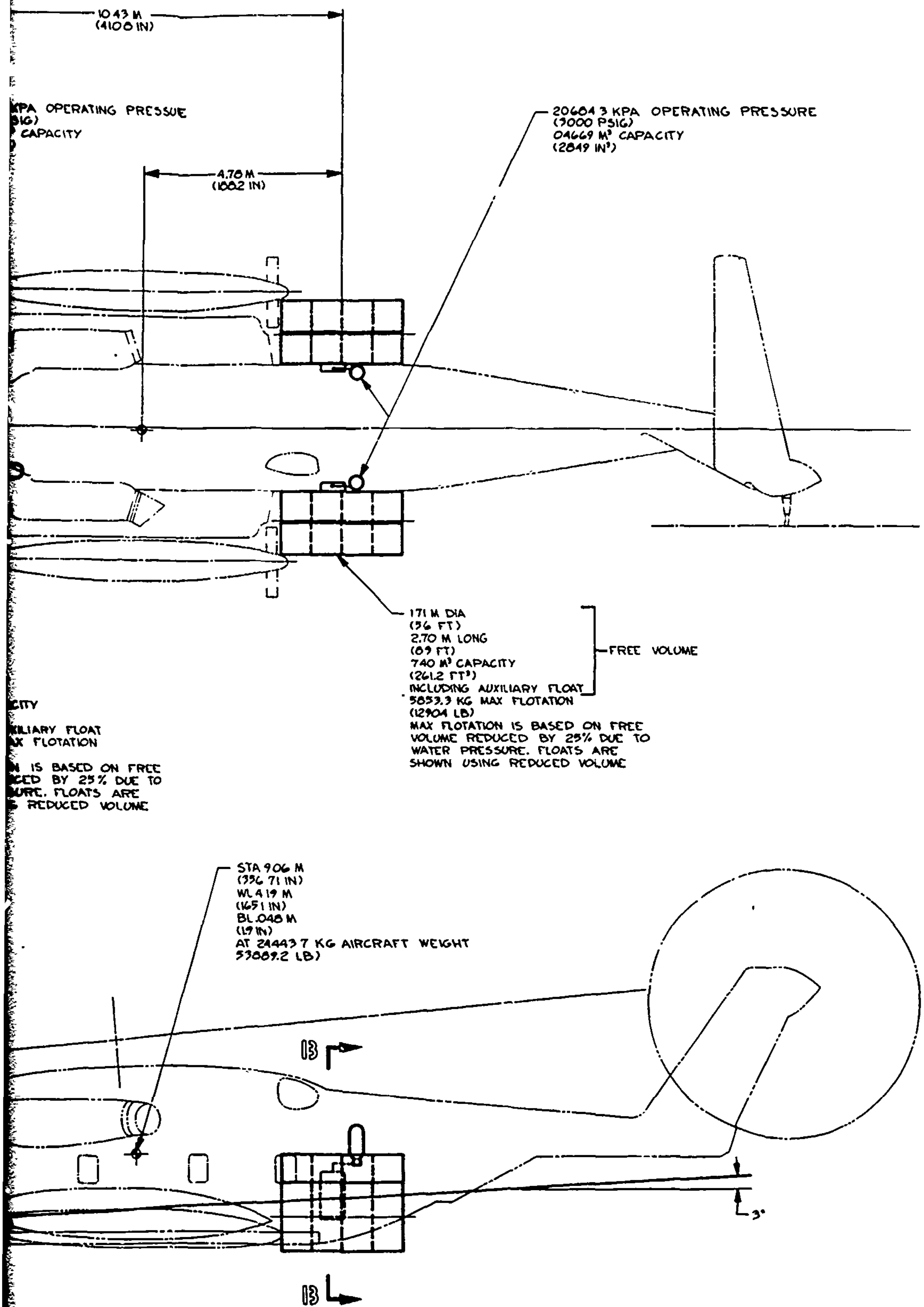


SECTION B – B
VIEW LOOKING AFT, LH SIDE
SCALE 1/10









N62269-80-C-0210

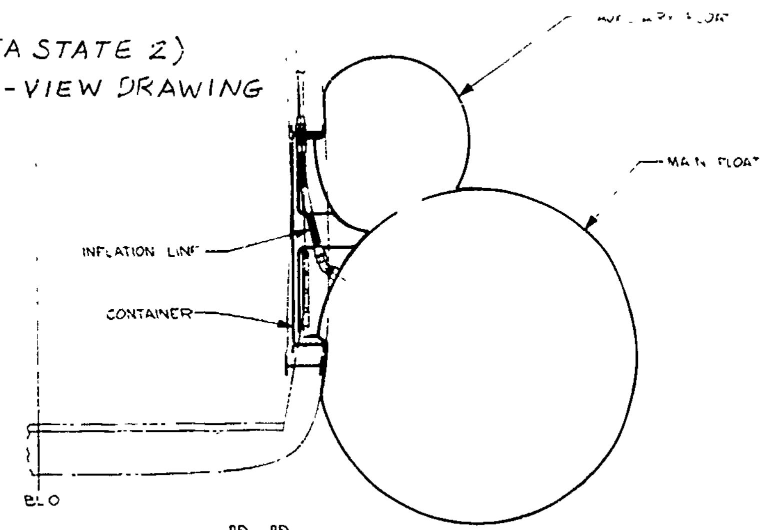
SIKORSKY AIRCRAFT

FLOTATION SYSTEM
SEA STATE 4
CH-53E

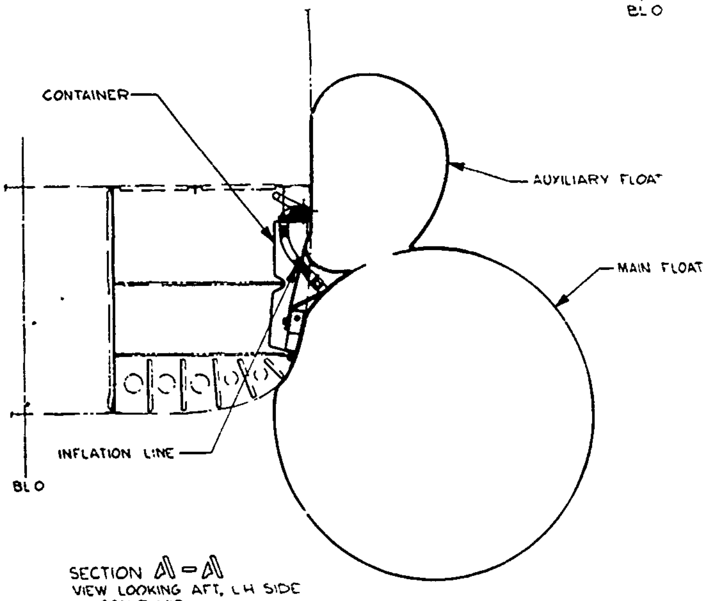
78286 S65-2

1 2

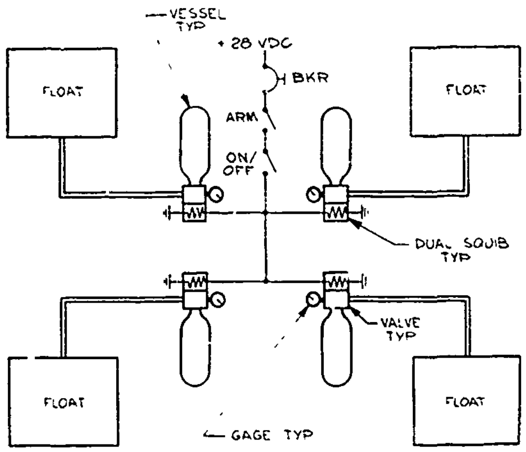
FIGURE 30 SYSTEM SIX (SEA STATE 2) DETAIL THREE-VIEW DRAWING



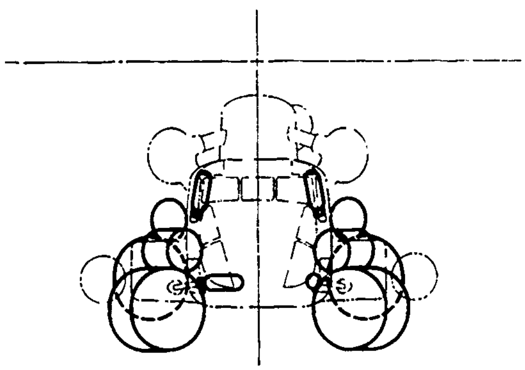
SECTION B-B
VIEW LOOKING AFT, LH SIDE
SCALE 1/10

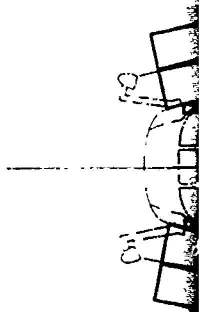


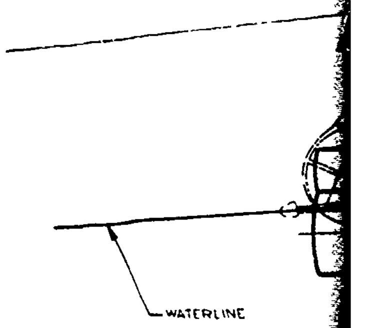
SECTION A-A
VIEW LOOKING AFT, LH SIDE
SCALE 1/10

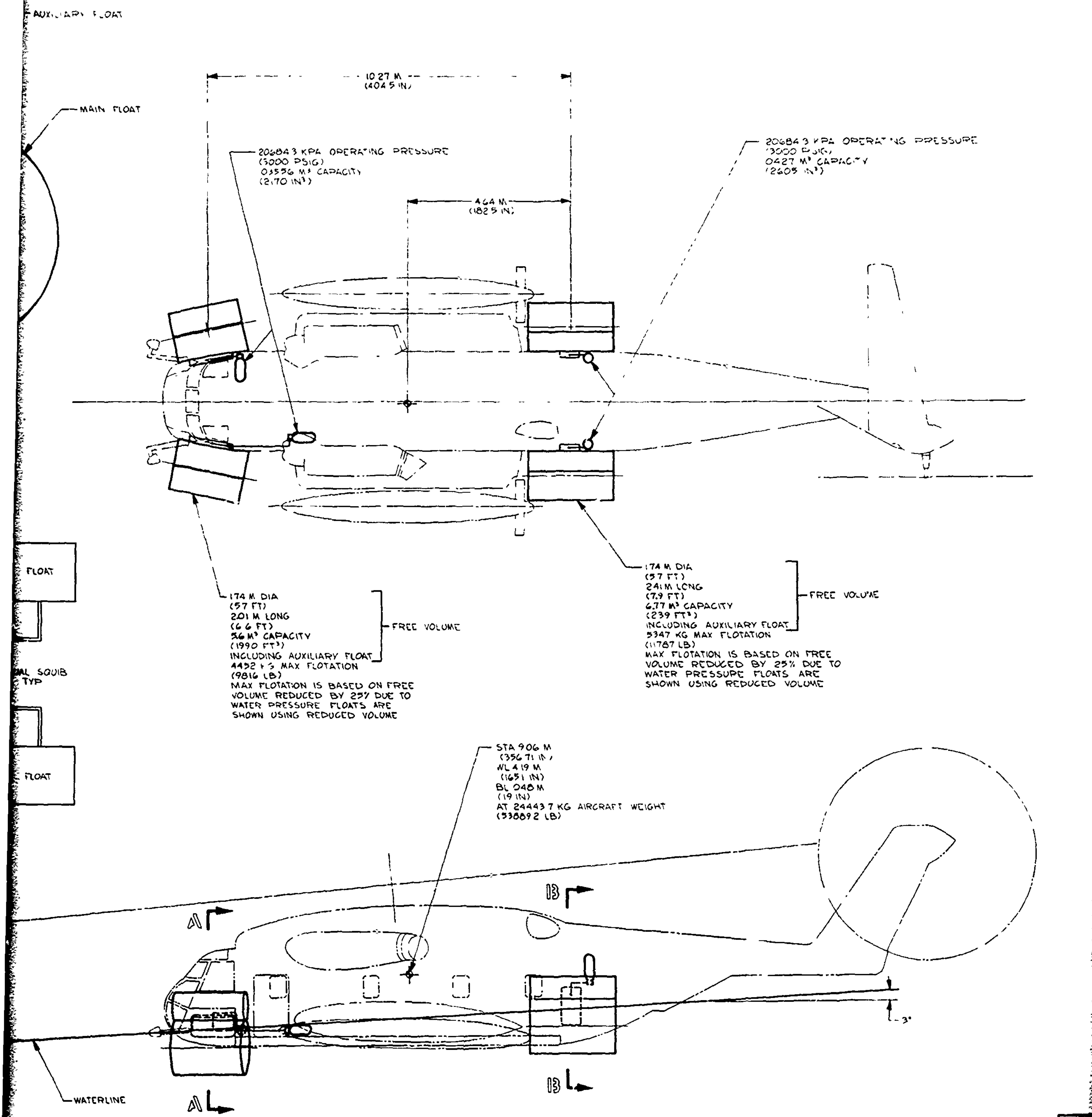


SYSTEM SCHEMATIC

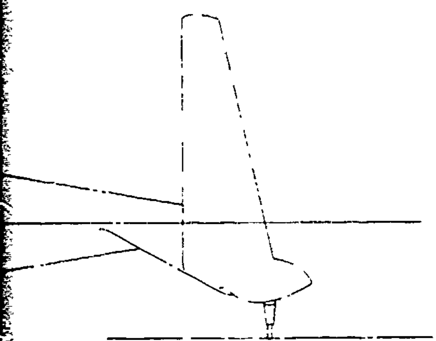







AUXILIARY FLOAT
MAIN FLOAT
10.27 M (404.5 IN)
20684.3 KPA OPERATING PRESSURE (3000 PSIG) 0.3556 M³ CAPACITY (2170 IN³)
20684.3 KPA OPERATING PRESSURE (3000 PSIG) 0.427 M³ CAPACITY (2605 IN³)
4.64 M (182.5 IN)
FLOAT
FLOAT
SQUIB TYP
1.74 M DIA (5.7 FT) 2.01 M LONG (6.6 FT) 56 M³ CAPACITY (1990 FT³) INCLUDING AUXILIARY FLOAT
FREE VOLUME
4452 KG MAX FLOTATION (9816 LB)
MAX FLOTATION IS BASED ON FREE VOLUME REDUCED BY 25% DUE TO WATER PRESSURE. FLOATS ARE SHOWN USING REDUCED VOLUME
1.74 M DIA (5.7 FT) 2.41 M LONG (7.9 FT) 6.77 M³ CAPACITY (239 FT³) INCLUDING AUXILIARY FLOAT
FREE VOLUME
5347 KG MAX FLOTATION (11787 LB)
MAX FLOTATION IS BASED ON FREE VOLUME REDUCED BY 25% DUE TO WATER PRESSURE. FLOATS ARE SHOWN USING REDUCED VOLUME
STA 9.06 M (356.71 IN) WL 4.19 M (165.1 IN) BL 0.48 M (19 IN) AT 24443.7 KG AIRCRAFT WEIGHT (53889.2 LB)
A
B
3°
WATERLINE

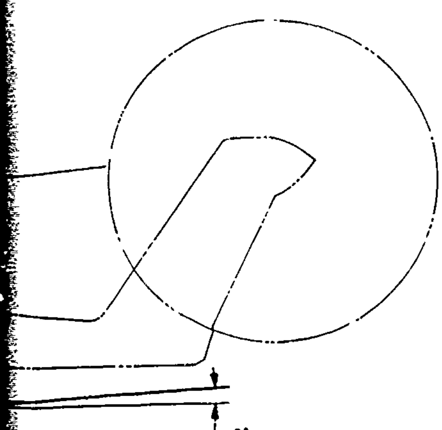
20684.3 KPA OPERATING PRESSURE
(3000 PSIG)
.0427 M^3 CAPACITY
(2605 IN^3)



FREE VOLUME

FLOAT
ION

ASED ON FREE
BY 25% DUE TO
FLOATS ARE
CED VOLUME



N62269-80-C-0210	SIKORSKY AIRCRAFT
	FLOTATION SYSTEM SEA STATE 2 CH-53E
	78286 | S65-3

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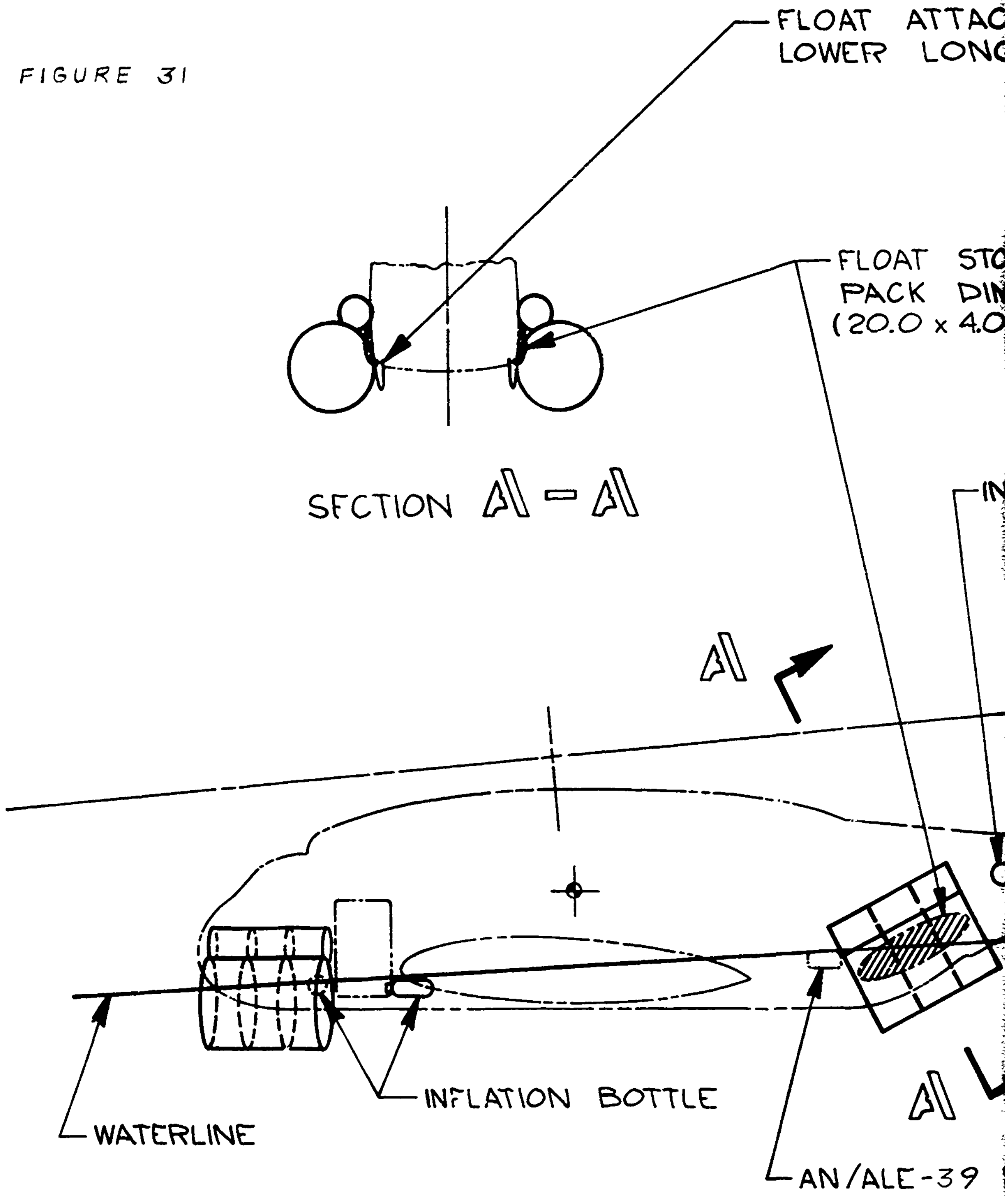
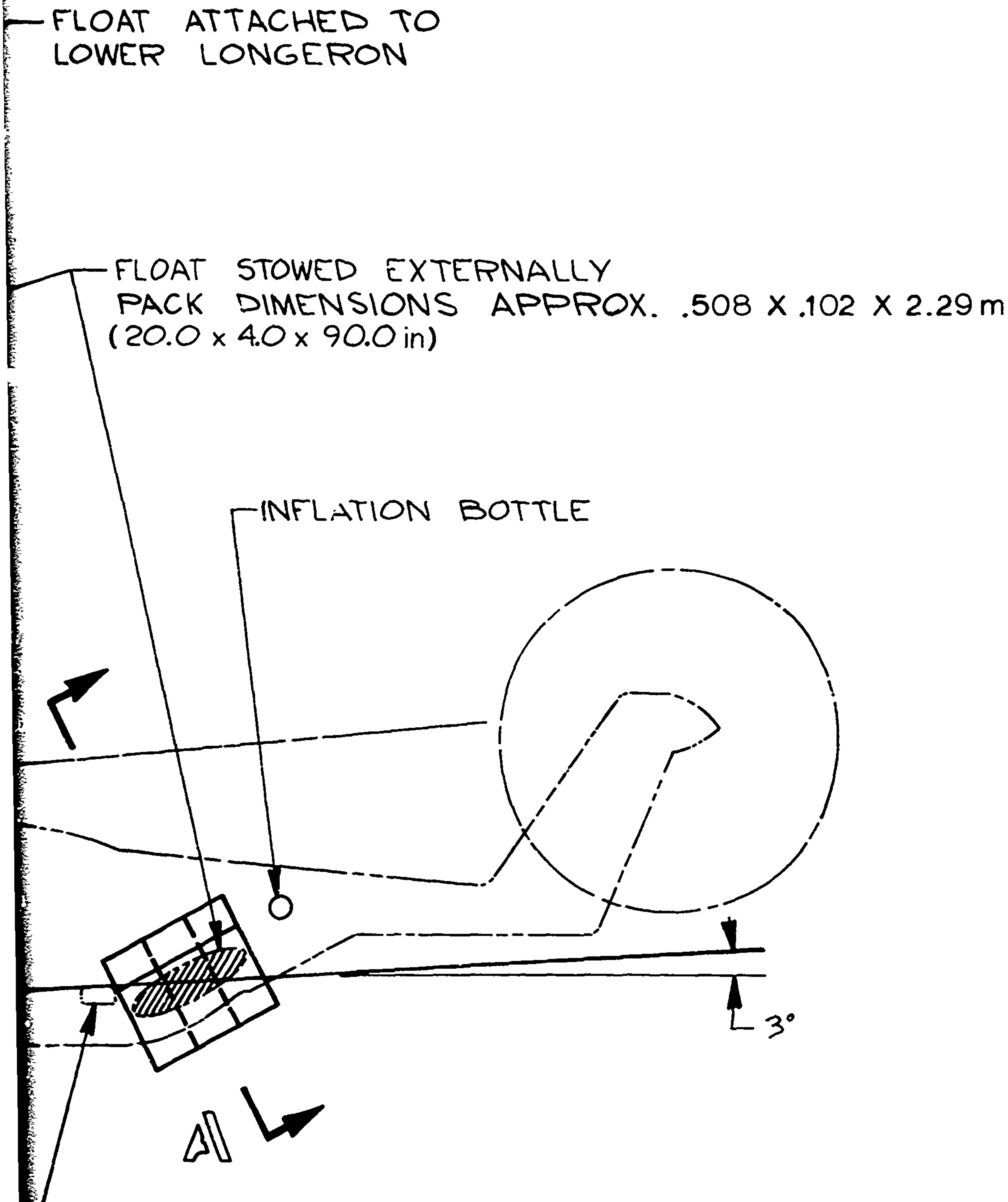
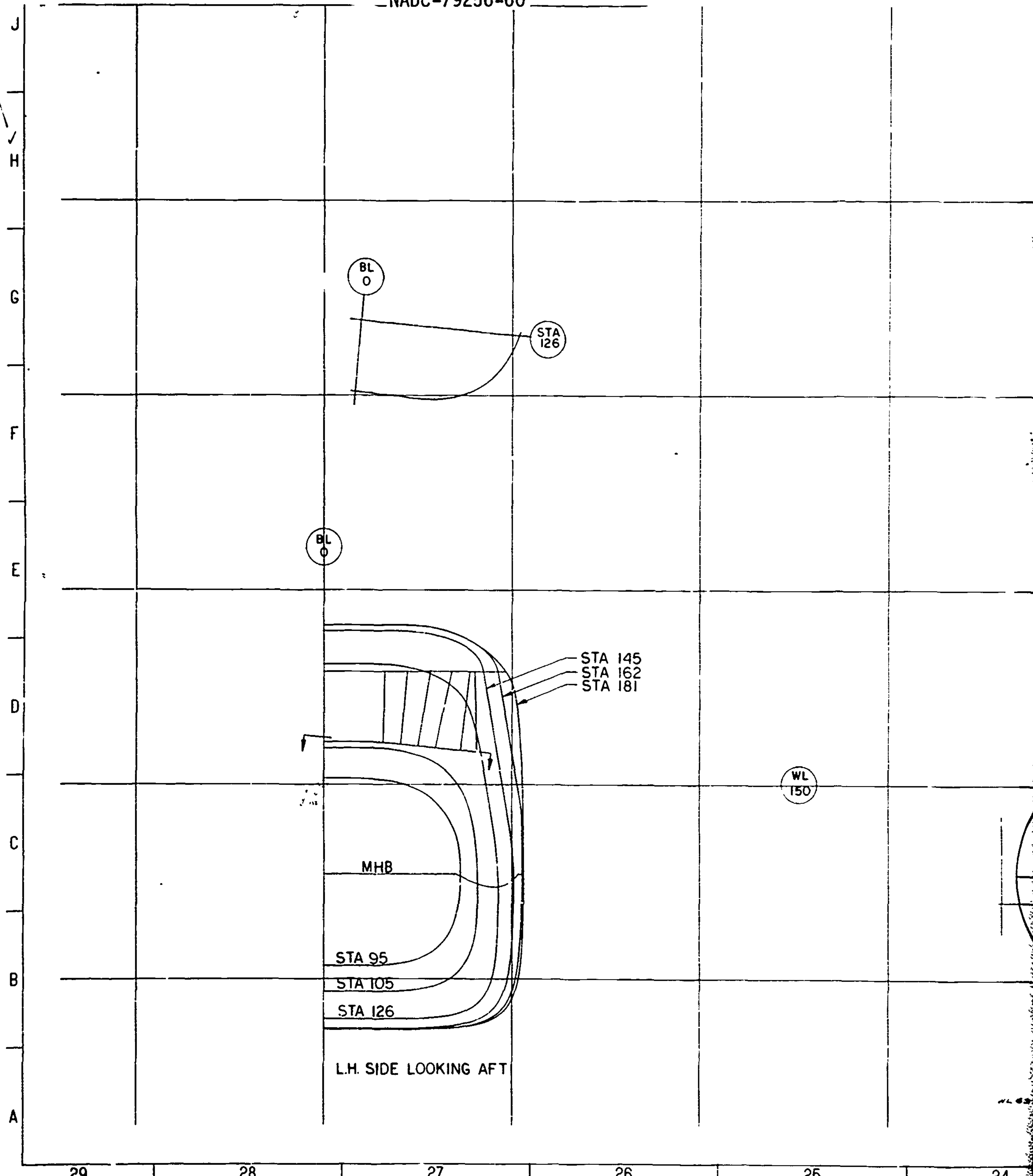
FIGURE 31

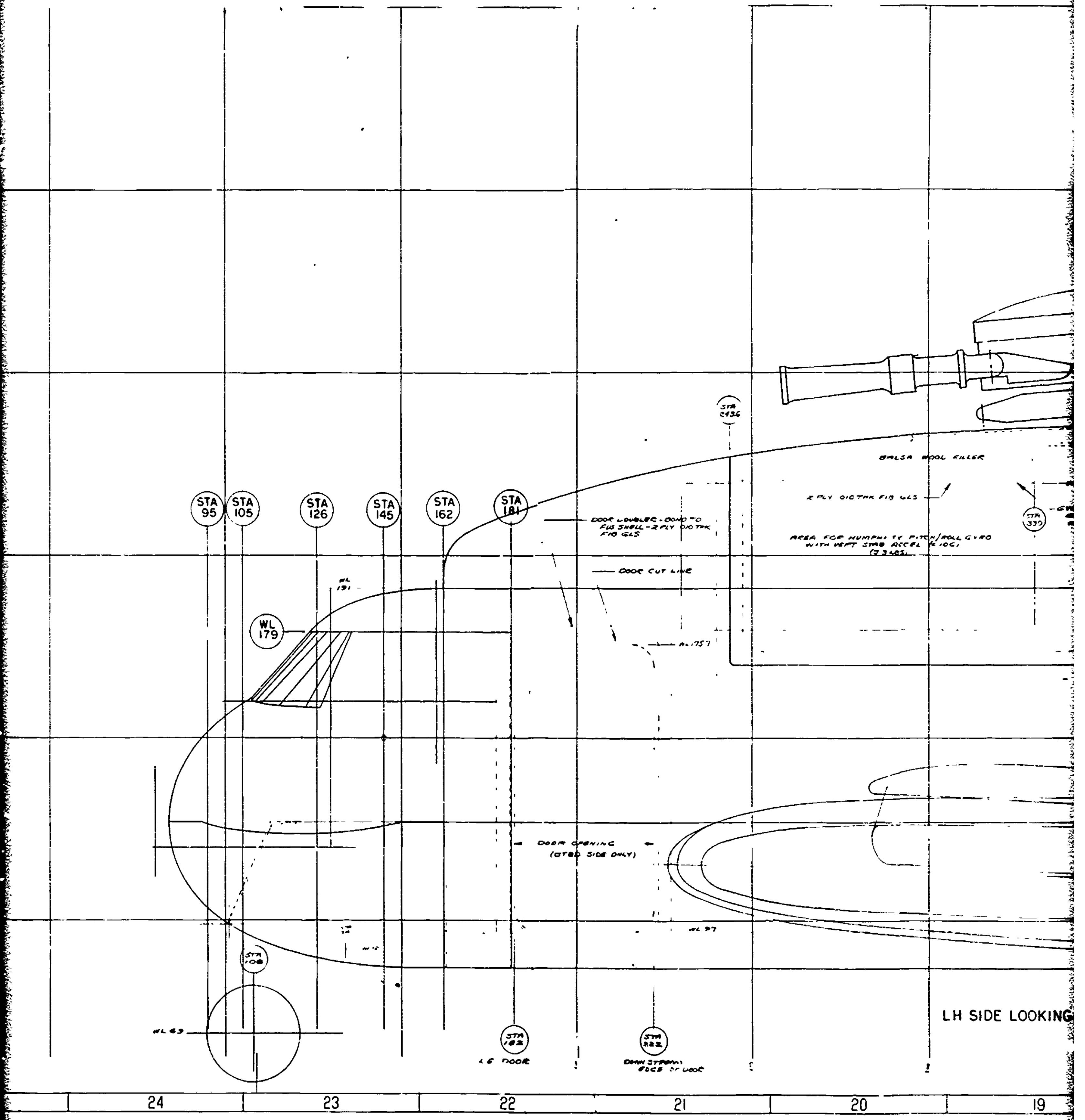


ALTERNATE FLOAT CONFIGURATION
WITH AN/ALE-39 DISPENSER

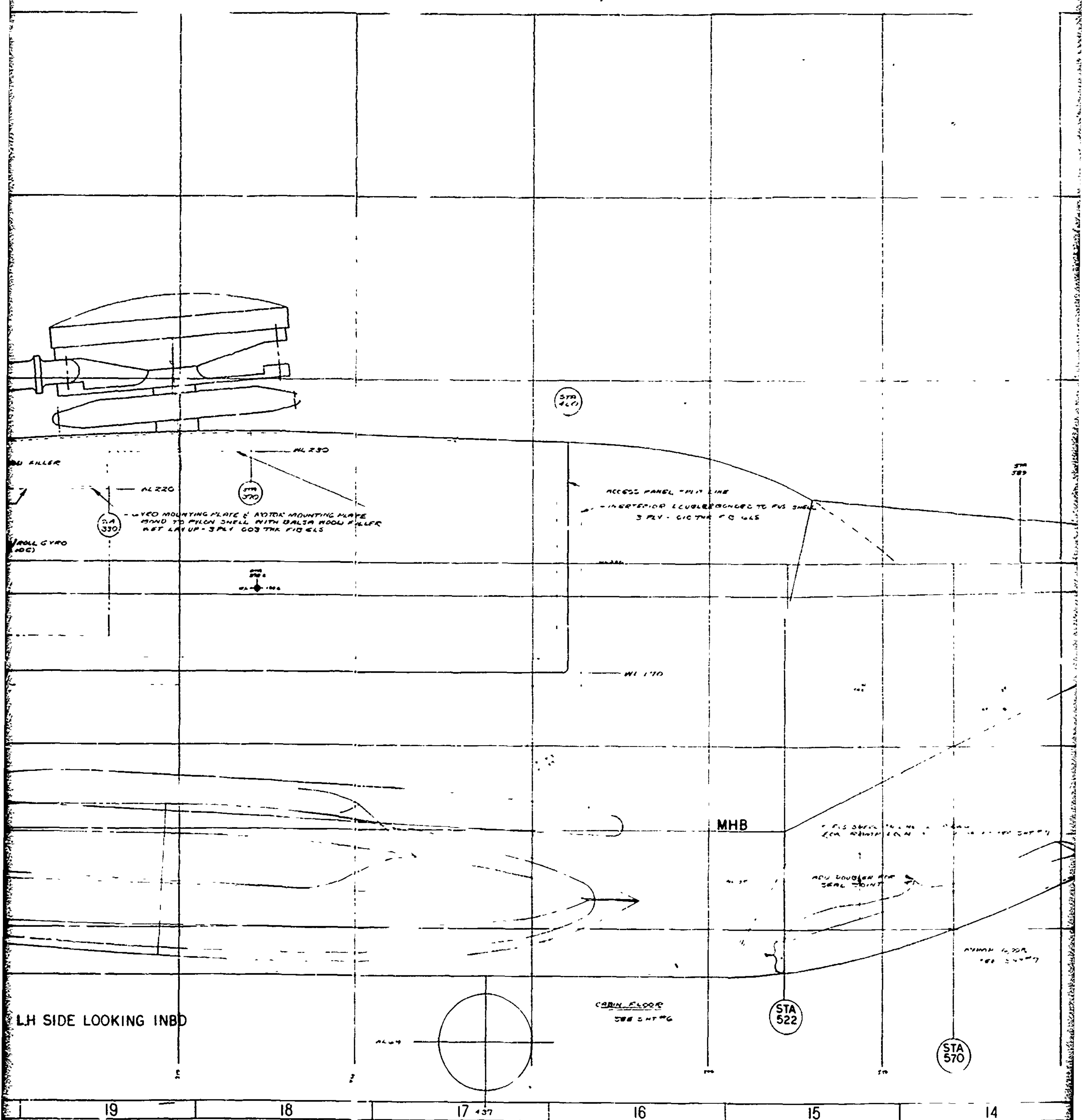


NFIGURATION FOR AIRCRAFT
PENS_R

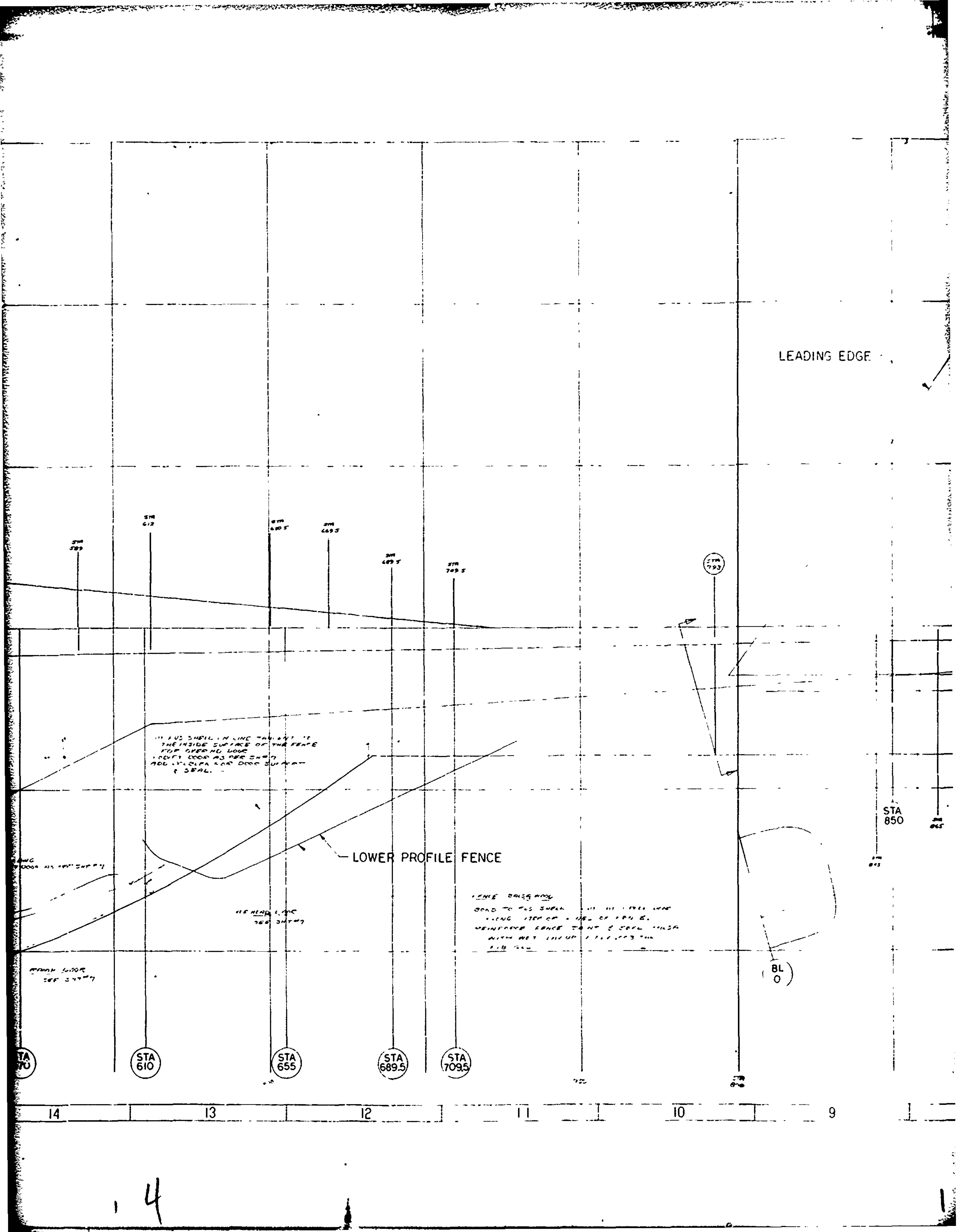

J
H
G
F
E
D
C
B
A
BL
0
STA
126
BL
0
STA 145
STA 162
STA 181
WL
150
MHB
STA 95
STA 105
STA 126
L.H. SIDE LOOKING AFT
29
28
27
26
25
24


STA 95
STA 105
STA 126
STA 145
STA 162
STA 181
WL 179
WL 191
STA 2436
BALSA WOOD FILLER
2 PLY .010 THK FIB GLS
DOOR DOUBLER - BOND TO FUS SHELL - 2 PLY .010 THK FIB GLS
AREA FOR HUMPHREY PITCH/ROLL GYRO WITH VERT STAB ACCEL
DOOR CUT LINE
WL 175.7
STA 330
DOOR OPENING (STBD SIDE ONLY)
WL 97
STA 108
WL 63
STA 182
C DOOR
STA 222
DOWN STREAM EDGE OF DOOR
LH SIDE LOOKING
24
23
22
21
20
19

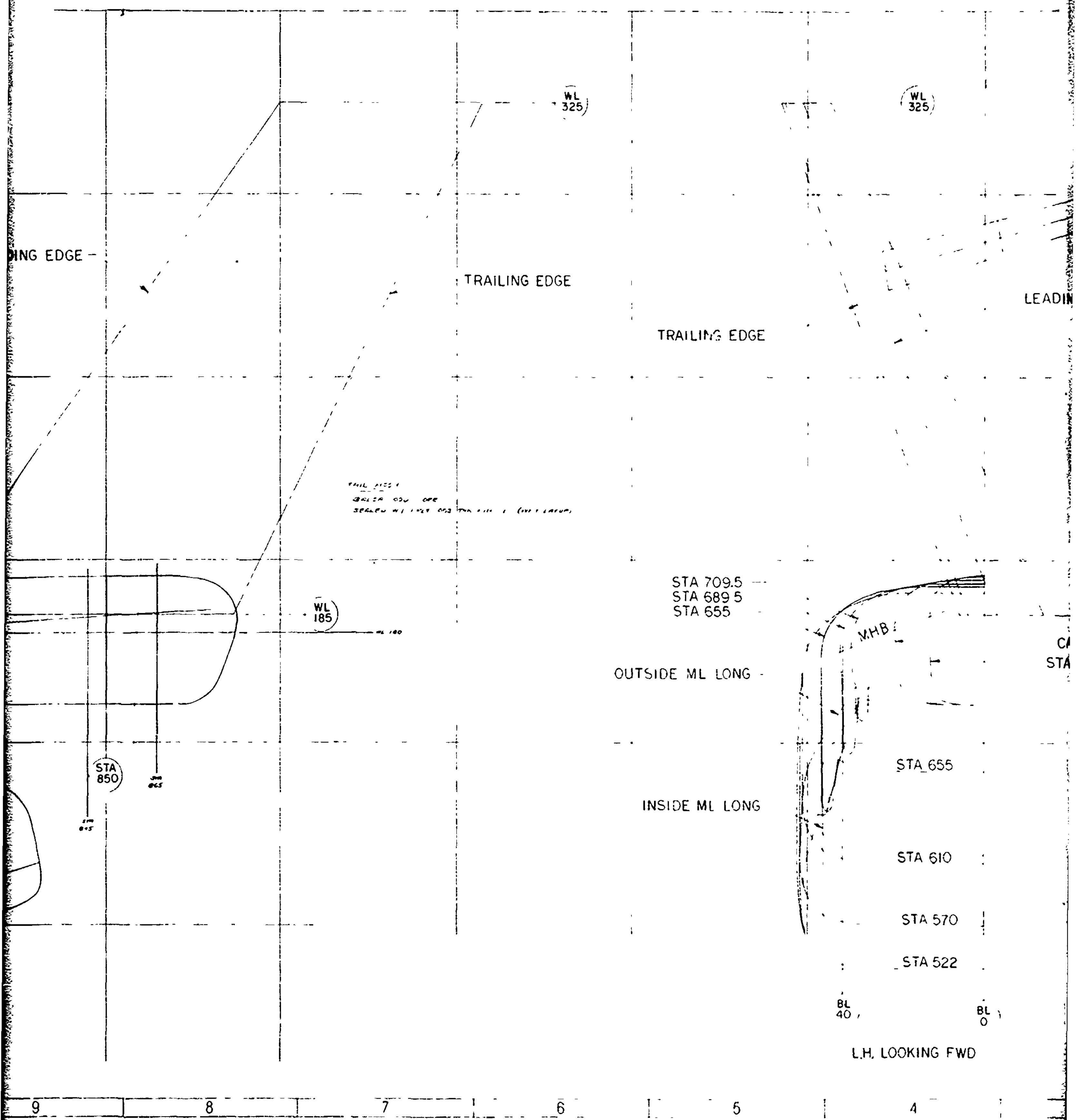
, 2


LH SIDE LOOKING INBD
MHB
STA 522
STA 570
CABIN FLOOR
19
18
17
16
15
14

13



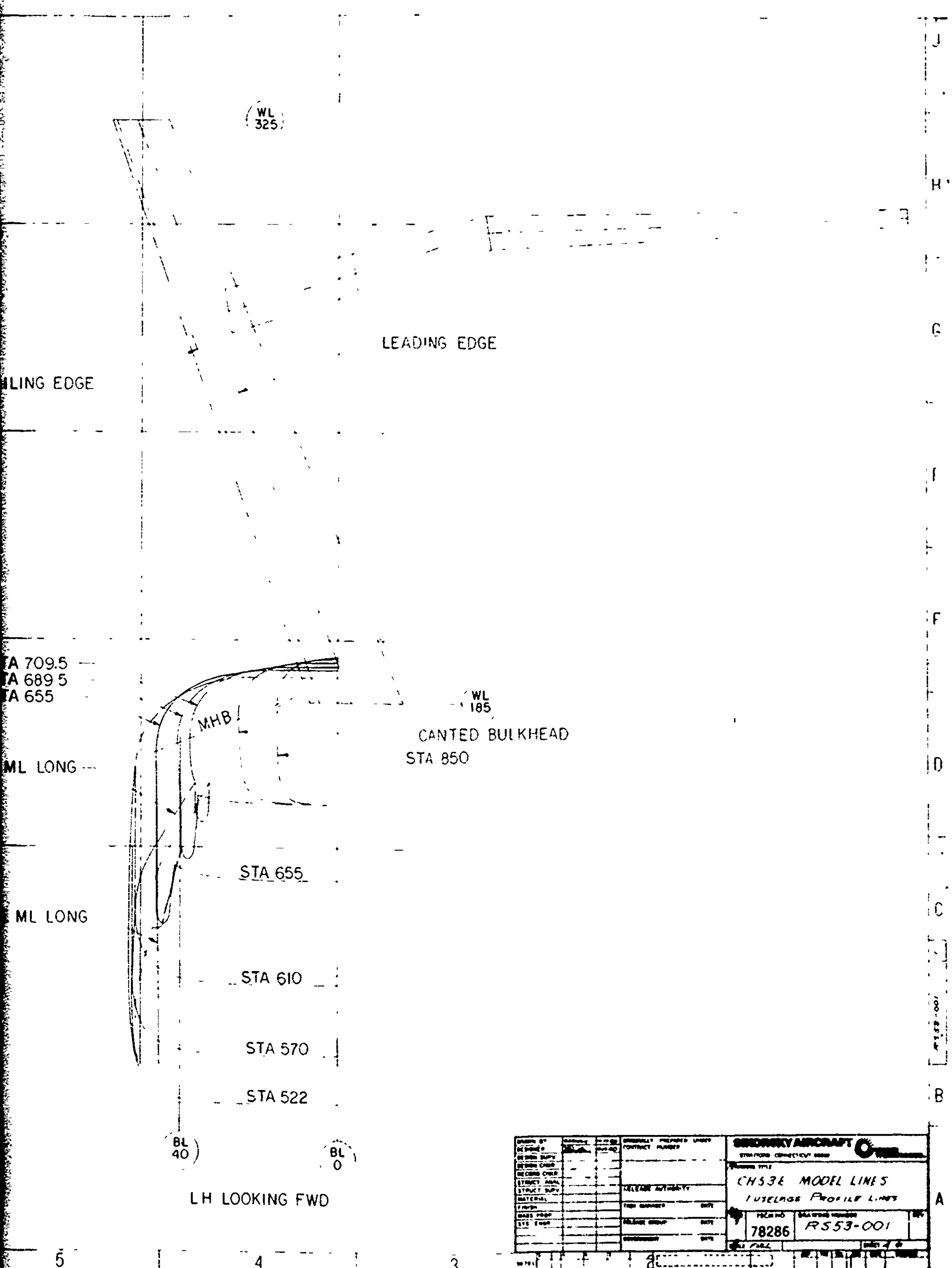
LEADING EDGE
LOWER PROFILE FENCE
STA 610
STA 655
STA 689.5
STA 709.5
STA 850
BL 0
14
13
12
11
10
9



WL 325
WL 325
ING EDGE
TRAILING EDGE
TRAILING EDGE
LEADIN
WL 185
STA 709.5
STA 689 5
STA 655
MHB
OUTSIDE ML LONG
INSIDE ML LONG
STA 850
STA 655
STA 610
STA 570
STA 522
BL 40
BL 0
L.H. LOOKING FWD
9
8
7
6
5
4

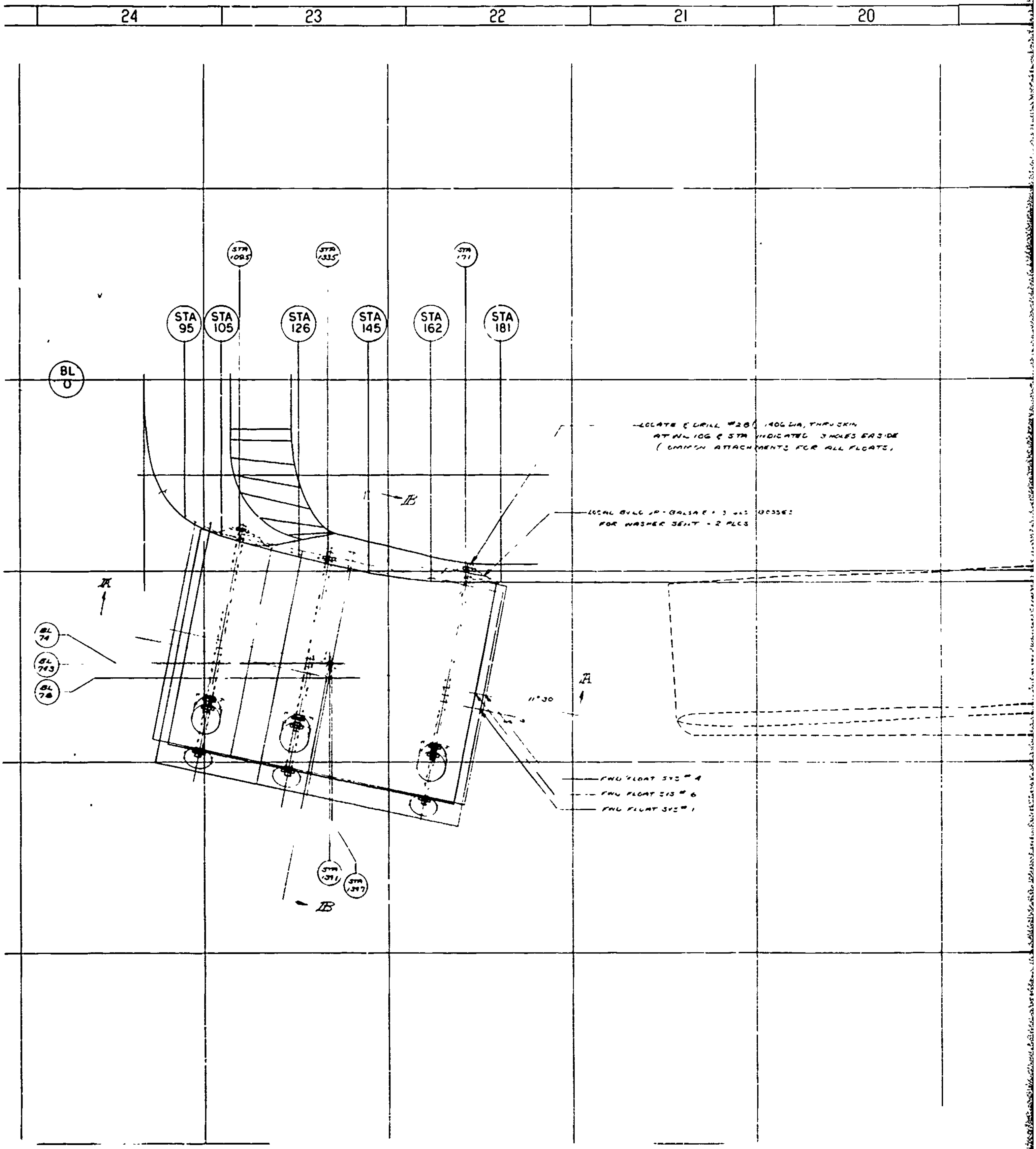
15

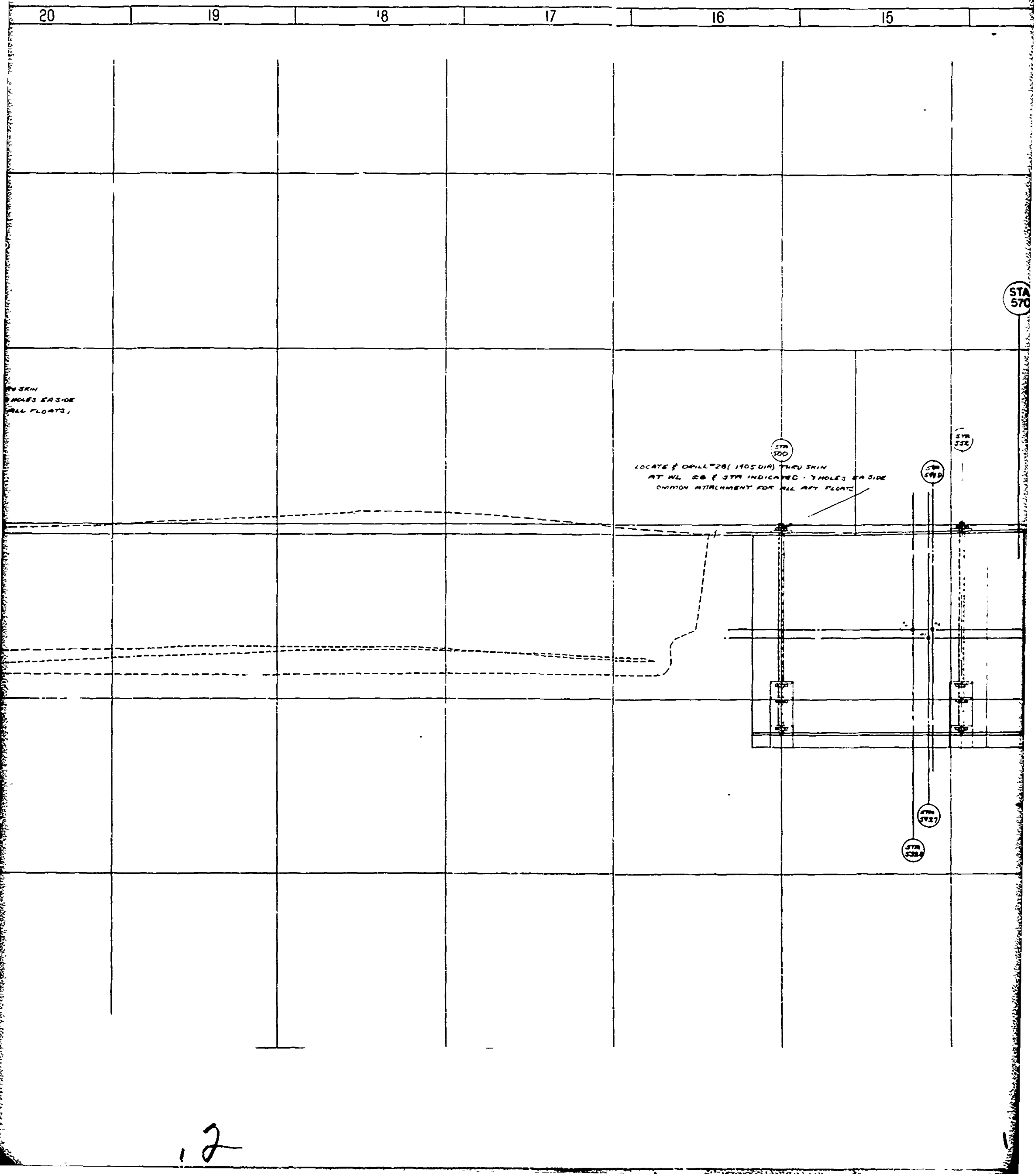
1

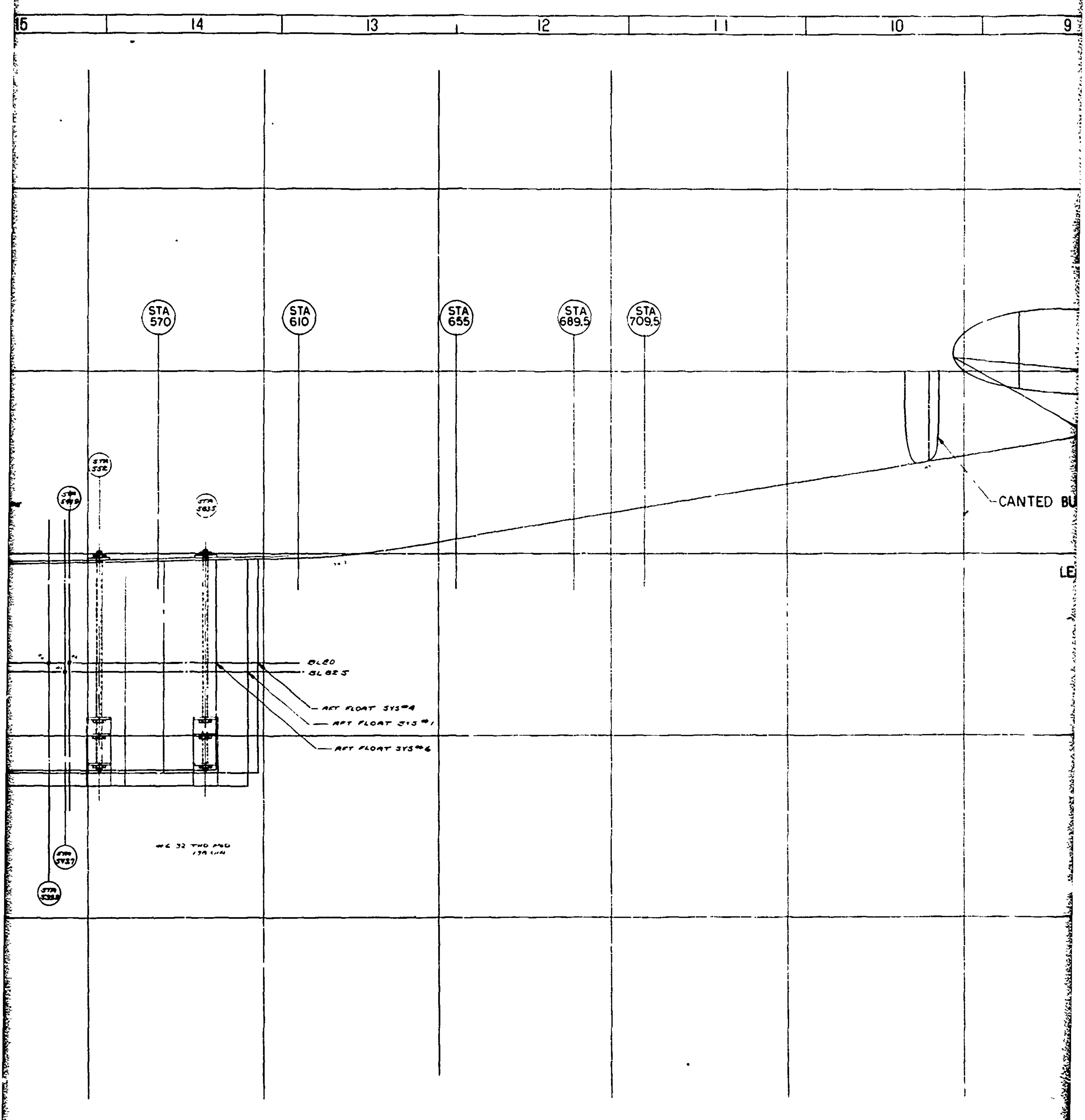

WL 325
LEADING EDGE
LING EDGE
A 709.5
A 689 5
A 655
WL 185
MHB
CANTED BULKHEAD
STA 850
ML LONG
ML LONG
STA 655
STA 610
STA 570
STA 522
BL 40
BL 0
L H LOOKING FWD
J
H
G
F
D
C
B
A
5
4
3
SIKORSKY AIRCRAFT
CH53E MODEL LINES
FUSELAGE PROFILE LINES
78286
RS53-001

UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

FIGURE 33

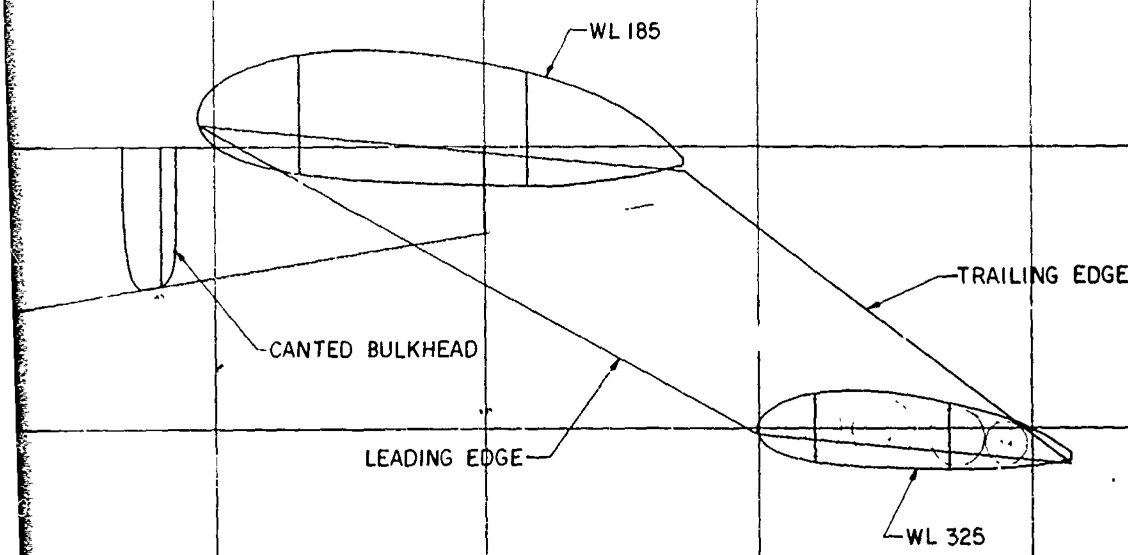



20
19
18
17
16
15
STA 570
STA 500
STA 552
LOCATE & DRILL #28 (.1405 DIA) THRU SKIN
AT WL 28 & STA INDICATED - 3 HOLES EA SIDE
OMMON ATTACHMENT FOR ALL AFT FLOATS
RU SKIN
HOLES EA SIDE
ALL FLOATS.


15
14
13
12
11
10
9
STA 570
STA 610
STA 655
STA 689.5
STA 709.5
CANTED BU
LE
BL 60
BL 82.5
AFT FLOAT SYS #4
AFT FLOAT SYS #1
AFT FLOAT SYS #6

13

10	9	8	7	6



NOTE:
FLOAT INSTALLATION INCLUDED
SEE SEC 23 & 14
& SHTS #10 & 11

CH53E MODEL LINES
FUSELAGE · TOP VIEW w/ TAIL

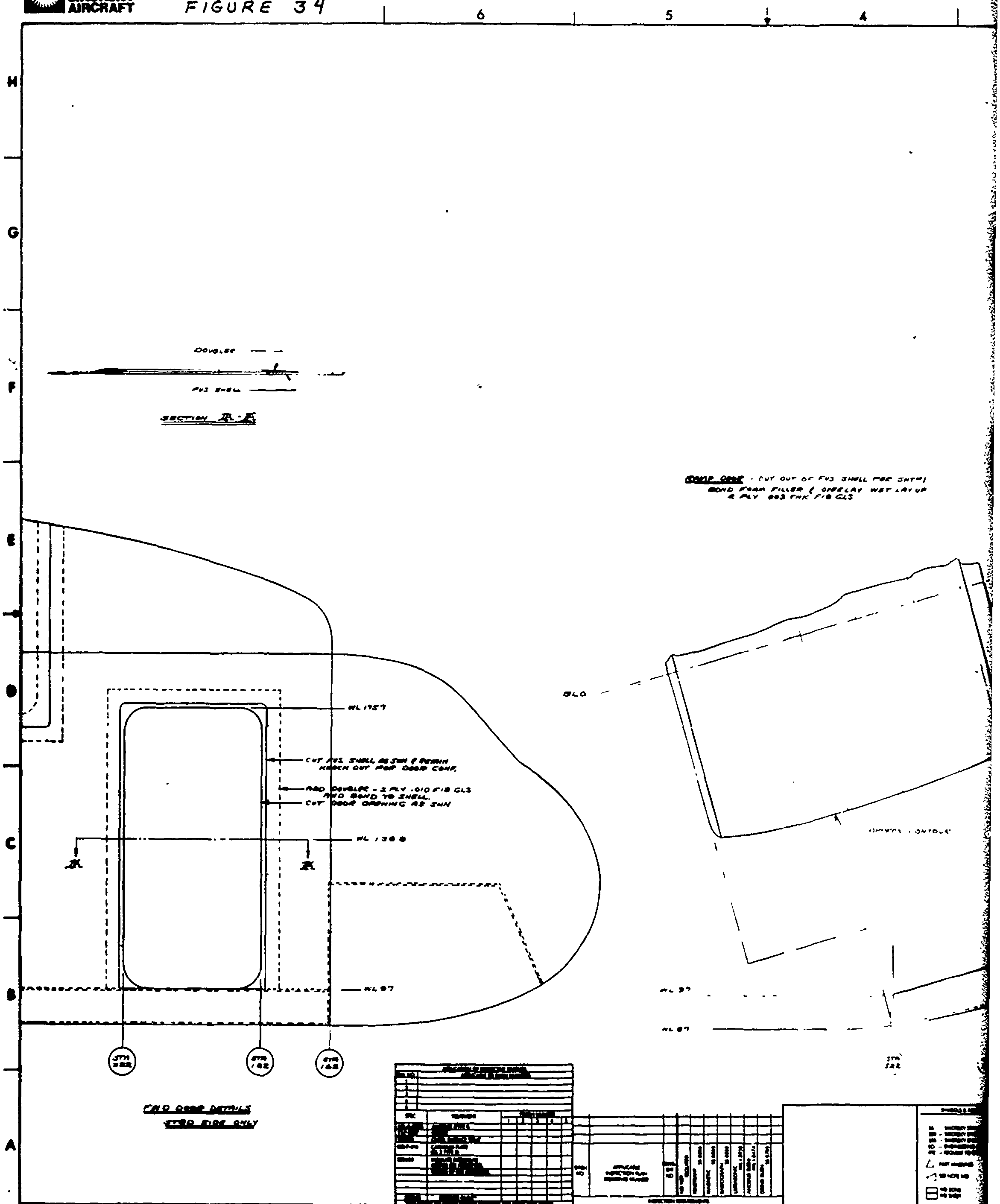
78286

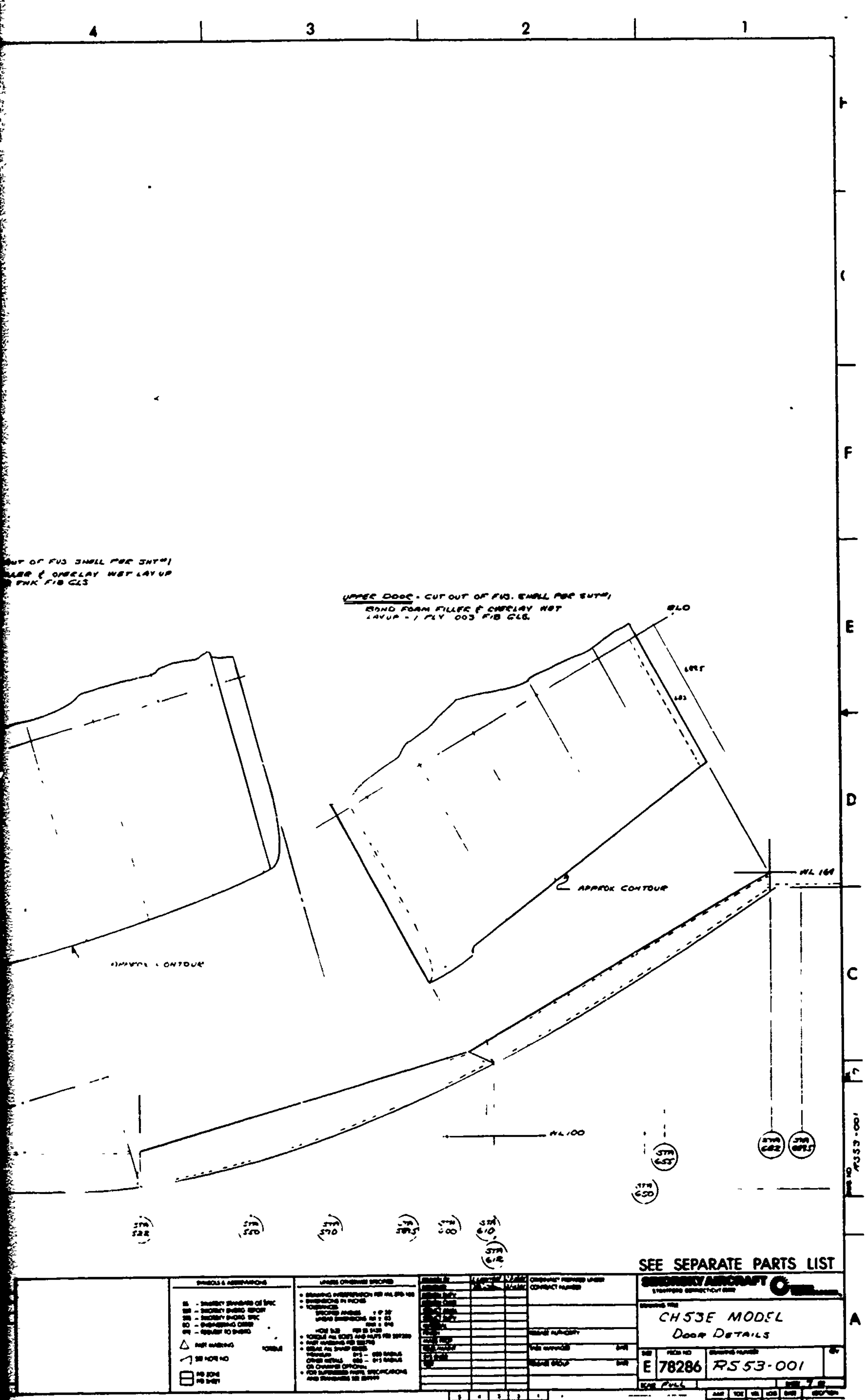
RS53-001

SCALE FULL

UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

FIGURE 34

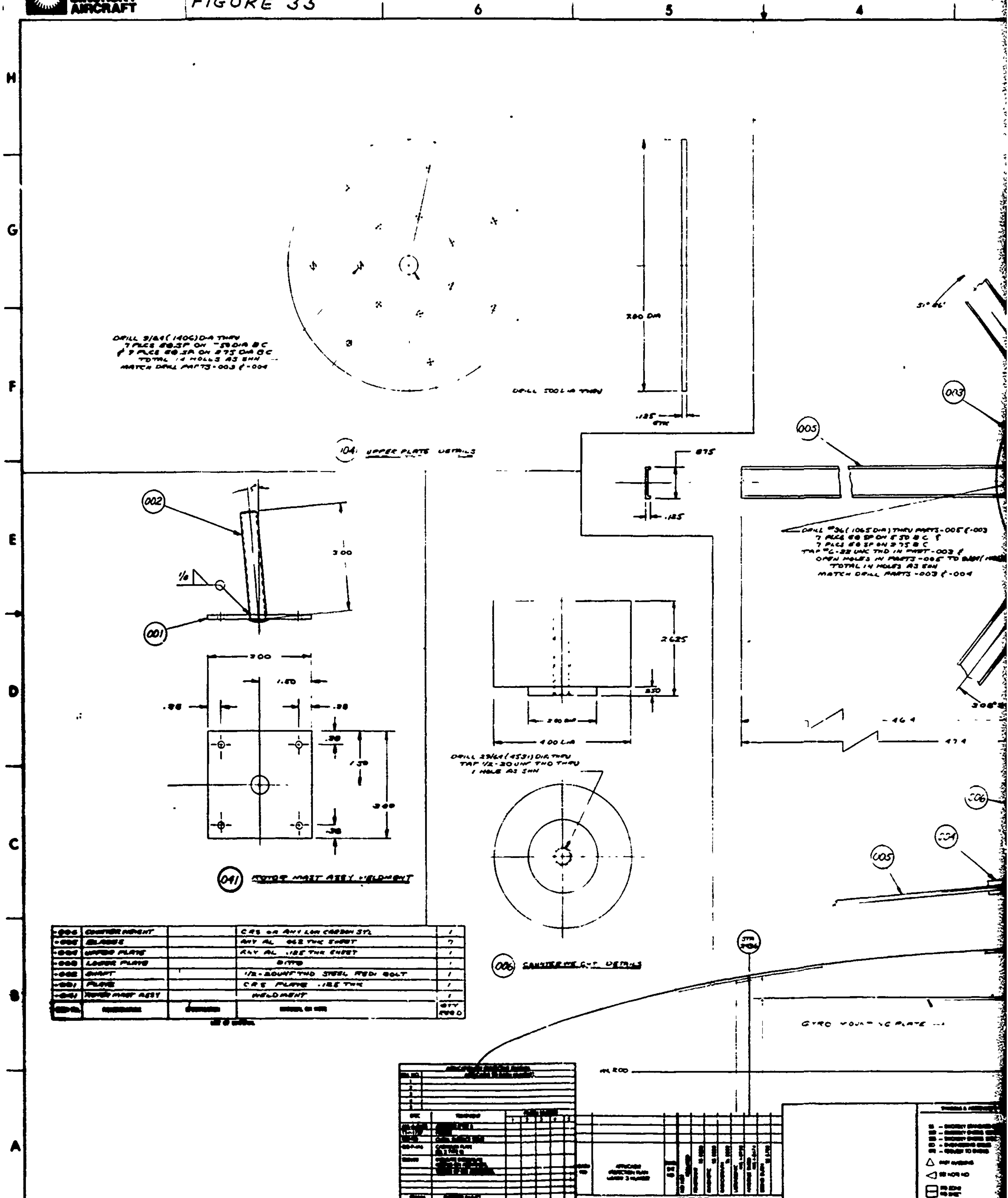


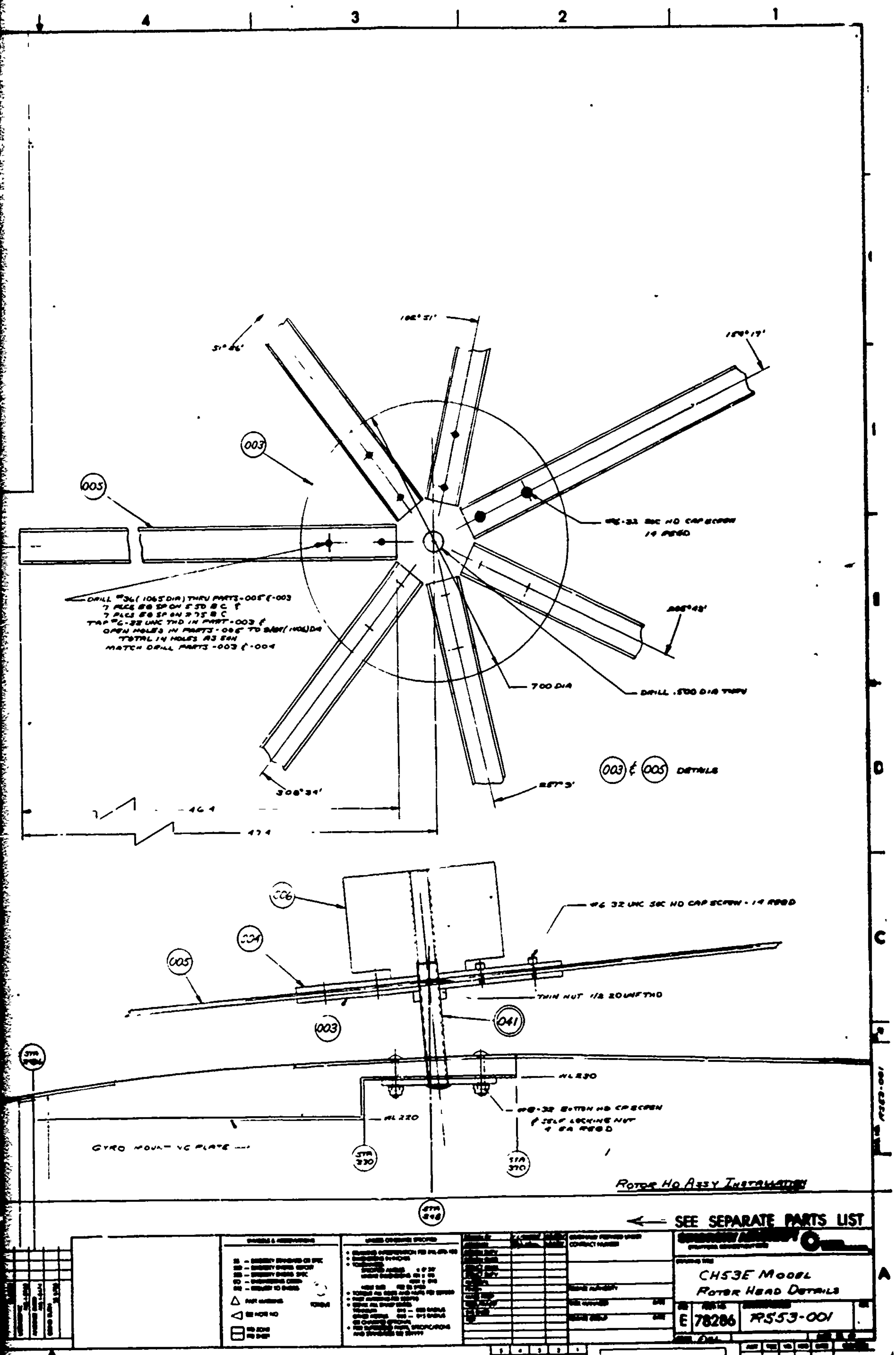

4
3
2
1
UPPER DOOR - CUT OUT OF FUS. SHELL PER SHT #1
BOND FOAM FILLER & OVERLAY WET
LAYUP - 1 PLY 003 FIB GLS.
APPROX CONTOUR
WL 164
WL 100
SEE SEPARATE PARTS LIST
CH53E MODEL
Door Details
E
78286
RS53-001
FULL

1 2

UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

FIGURE 35



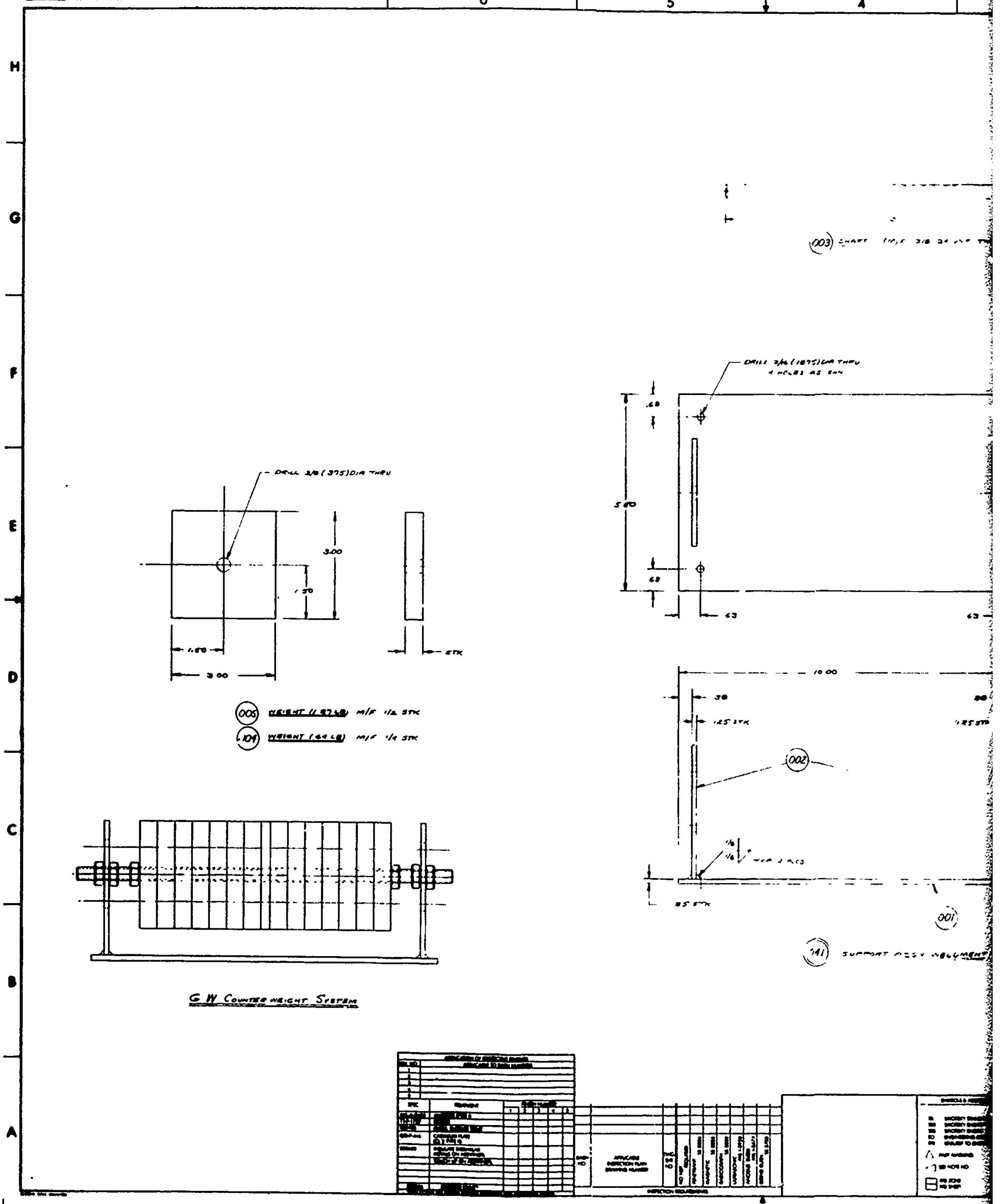


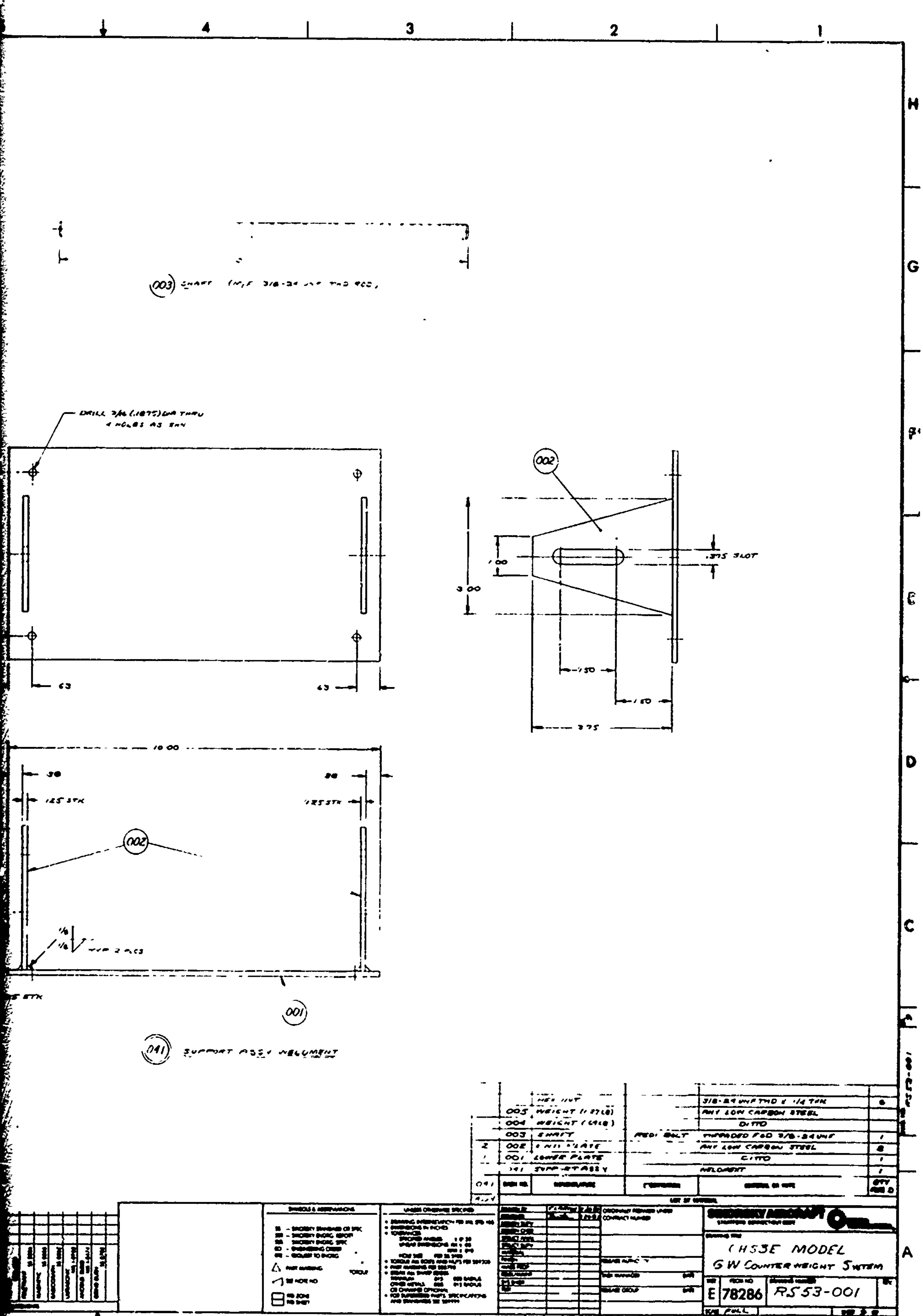
003
005
700 DIA
DRILL .500 DIA THRU
003 & 005 DETAILS
006
041
THIN NUT 1/2 20UNF THD
WL 230
WL 220
GYRO MOUNT'G PLATE
ROTOR HD ASSY INSTALLATION
SEE SEPARATE PARTS LIST
CH53E MODEL
ROTOR HEAD DETAILS
E 78286 RS53-001

2

UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

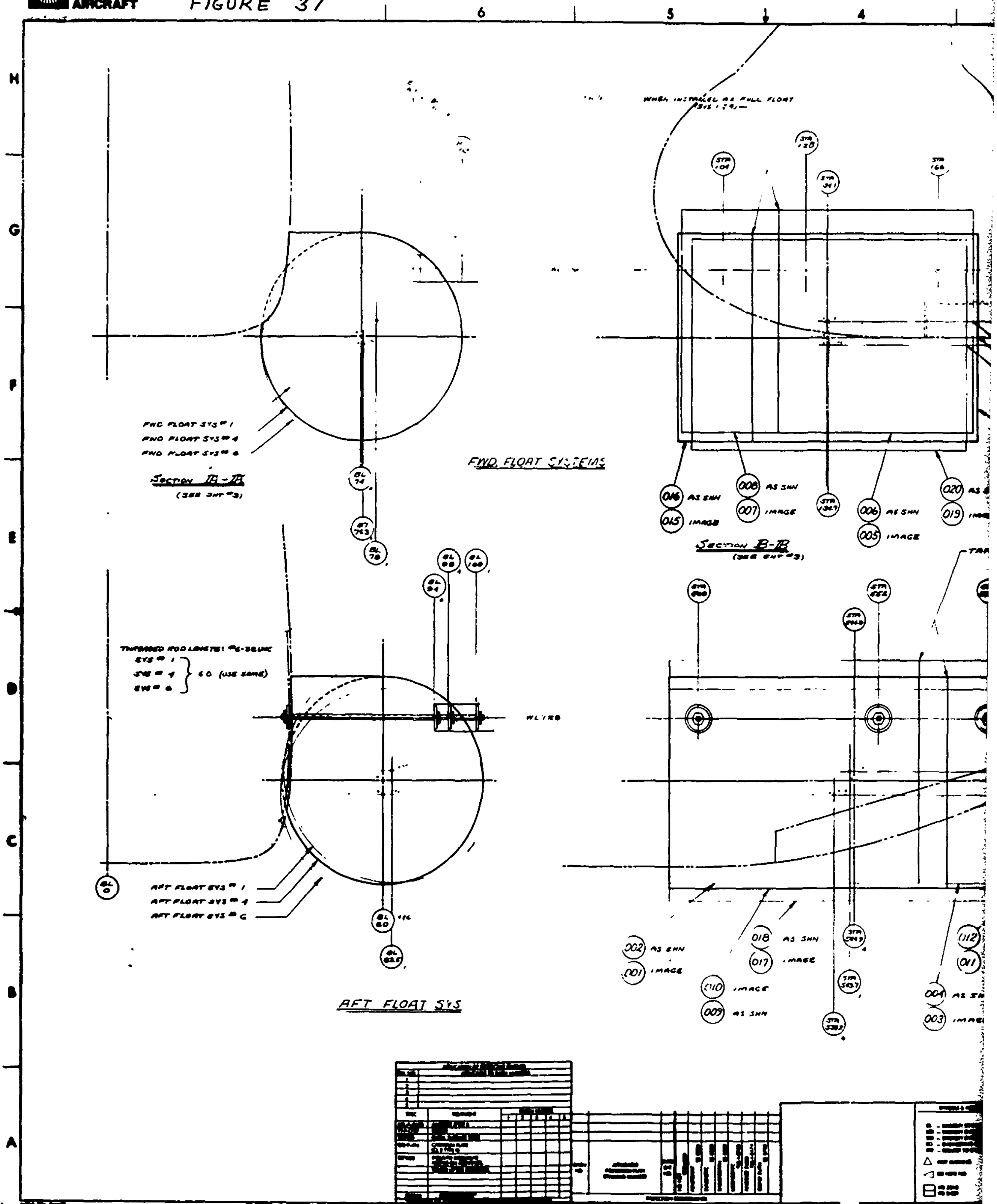
FIGURE 36

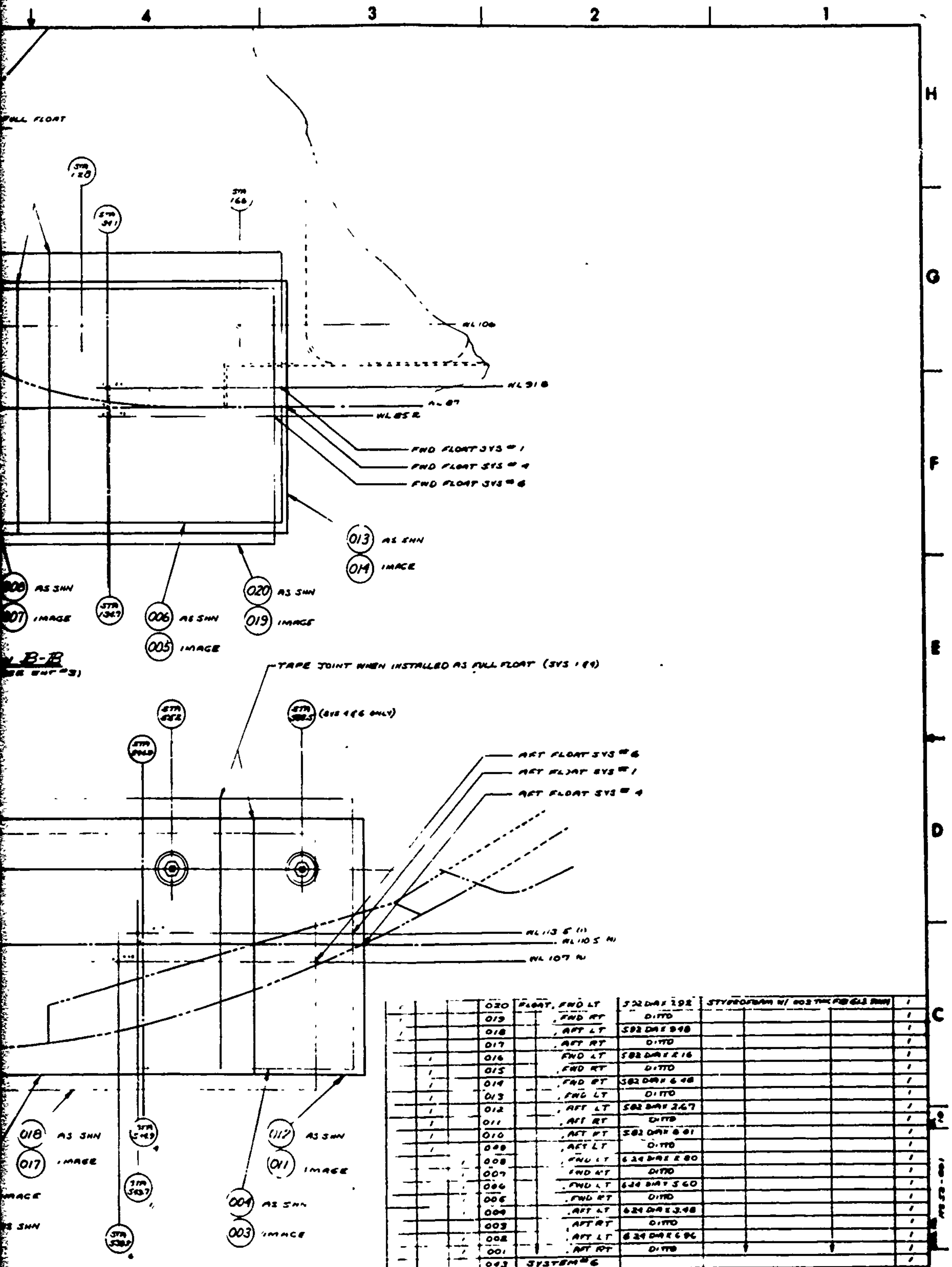




(003) SHAFT
DRILL 3/16 (.1875) DIA THRU
4 HOLES AS SHN
(002)
.375 SLOT
1.00
3.00
.150
.150
.375
.63
.63
10.00
.38
.38
.125 STK
.125 STK
(002)
1/16
1/16
TYP 2 PLCS
(001)
(041) SUPPORT ASSY WELDMENT
HEX NUT
005 WEIGHT
004 WEIGHT
003 SHAFT
002 END PLATE
001 LOWER PLATE
041 SUPPORT ASSY
3/8-24 UNF THD X 1/4 THK
ANY LOW CARBON STEEL
DITTO
THREADED ROD 3/8-24 UNF
ANY LOW CARBON STEEL
DITTO
WELDMENT
CH53E MODEL
GW COUNTERWEIGHT SYSTEM
E
78286
RS53-001
FULL
H
G
F
E
D
C
A
4
3
2
1

FIGURE 37


FWD. FLOAT SYSTEMS
AFT FLOAT SYS
SECTION B-B
WHEN INSTALLED AS FULL FLOAT
AS SHN
IMAGE

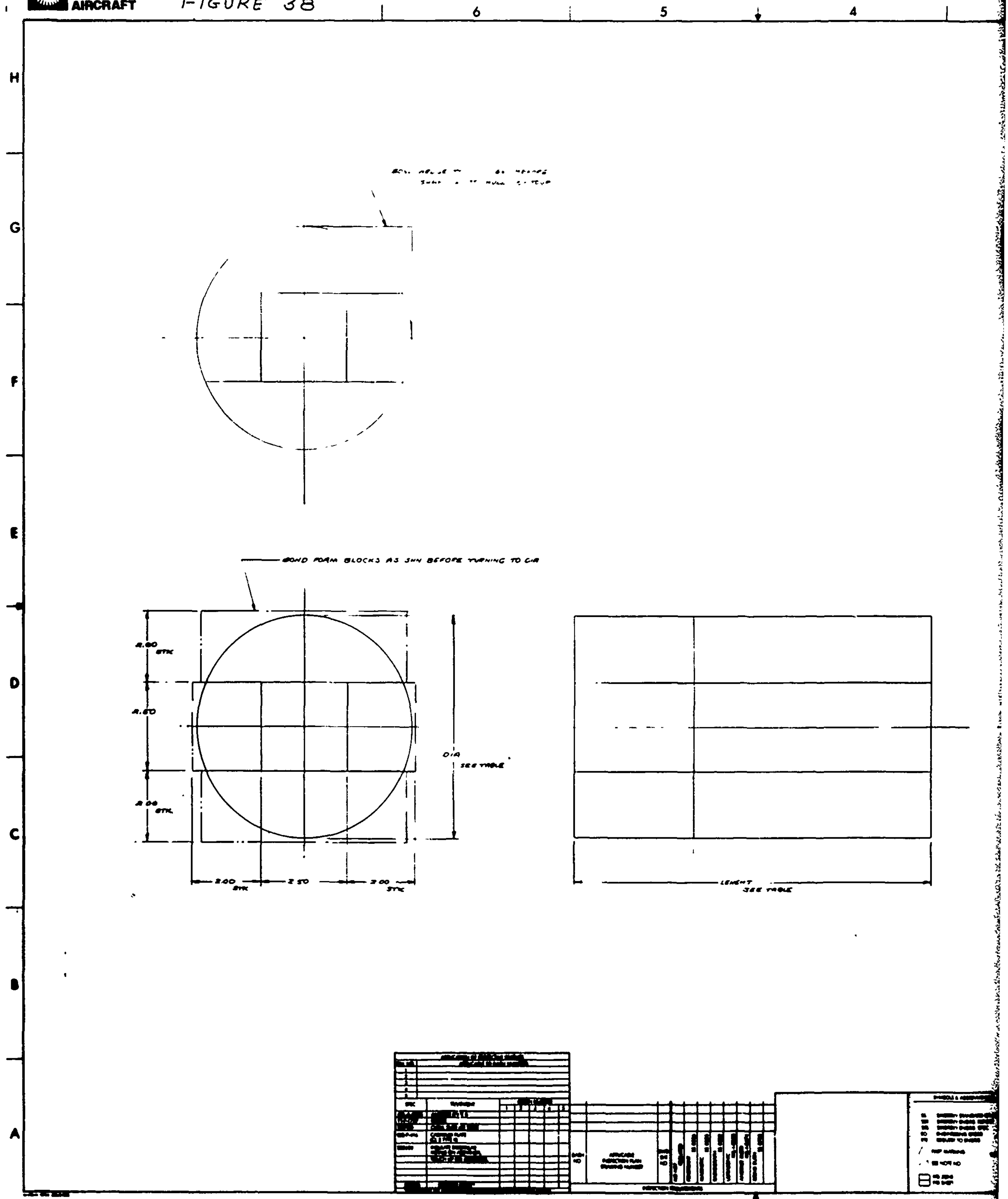


043	042	041	[illegible]	[illegible]	[illegible]	[illegible]	QTY REQD
/			020	FLOAT, FWD LT	5.32 DIA X 7.92	STYROFOAM W/ .003 THK FIBGLS SKIN	1
/			019	, FWD RT	DITTO		1
/			018	, AFT LT	5.82 DIA X 9.48		1
/			017	, AFT RT	DITTO		1
	/		016	FWD LT	5.82 DIA X 8.16		1
	/		015	, FWD RT	DITTO		1
	/		014	, FWD RT	5.82 DIA X 6.48		1
	/		013	, FWD LT	DITTO		1
	/		012	, AFT LT	5.82 DIA X 2.67		1
	/		011	, AFT RT	DITTO		1
	/		010	, AFT RT	5.82 DIA X 8.01		1
	/		009	, AFT LT	DITTO		1
		/	008	, FWD LT	6.24 DIA X 2.80		1
		/	007	FWD RT	DITTO		1
		/	006	, FWD LT	6.24 DIA X 5.60		1
		/	005	, FWD RT	DITTO		1
		/	004	, AFT LT	6.24 DIA X 3.48		1
		/	003	, AFT RT	DITTO		1
		/	002	, AFT LT	6.24 DIA X 6.96		1
		/	001	, AFT RT	DITTO		1
			043	SYSTEM # 6			1
			042	SYSTEM # 4			1
			041	SYSTEM # 1			1

CH53E MODEL
FLOAT DETAILS - SYS # 1,4,6

E 78286 RS53-001

FIGURE 38


BOND FORM BLOCKS AS SHN BEFORE TURNING TO DIA
2.00 STK
2.50
2.00 STK
DIA
SEE TABLE
LENGHT
SEE TABLE

	4	3	2	1	

SEE TABLE

DASH Nº	DIAMETER	LENGTH	
020 & 019	592	792	
018 & 017	592	948	
016 & 015	582	816	
014 & 013	582	648	
012 & 011	582	867	
010 & 009	582	601	
008 & 007	624	280	
006 & 005	624	560	
004 & 003	624	848	SHN
002 & 001	624	636	SHN

TOTAL 20 FLOATS

SHT #10 SEE SEPARATE PARTS LIST

CH53E MODEL
FLOAT DETAILS

E 78286 R553-001

2

14.0 APPENDIX A - REVIEW OF CH-53A/D HELICOPTER ACCIDENTS ON WATER

The accident data included herein was obtained from the Naval Safety Center, Norfolk, Va. Included are the reported statistics of ten accidents involving CH-53 Navy/Marine cargo helicopters and which occurred on water in the time period May, 1968 through June, 1979.

It should be noted that the author of this review did not participate in any on-site investigation of the reported accidents. Thus, little or no first-hand knowledge of the circumstances, occurrences, post-accident investigations or conclusions is available, nor is anything known about the pilots and crews or maintenance of the helicopters.

14.1 Accident Data

The computerized data made available by the Naval Safety Center, Norfolk, Virginia on CH-53 Navy/Marine helicopter accidents that occurred on water has been reviewed. It was found to contain limited information on eight accidents that resulted in the destruction of the helicopter and one which resulted in only limited damage when the helicopter struck, but did not enter, the water. Two additional accidents resulting in destruction of the helicopter were previously known to have occurred.

In August, 1980, Sikorsky personnel visited the Naval Safety Center to review the records of the ten accidents that resulted in the loss of the helicopters. The records of one of the accidents were not available because of litigation and the records of another was reported in summary form only.

The following data then constitutes the best available data on the subject accidents. The only way to obtain desired information not contained in the accident records would be to submit a questionnaire to the crew members involved, but this is considered beyond the scope of this investigation.

The ten accidents involving CH-53 helicopters on water are:

NO.	IDENTIFICATION	MODEL	LOCATION	TIME	TYPE OF ACCIDENT
1.	680501	CH-53A	S. Vietnam	Night	Flew into water at moderate speed
2.	691101	CH-53A	S. Vietnam	Night	Uncontrolled crash
3.	701030	CH-53D	S. Vietnam	Day	Rotating descent from hover
4.	730127	CH-53D	Phillipines	Dusk	Autorotation into water
5.	730318	CH-53D (MCM)	N. Vietnam	Day	Rotating descent with severe impact.
6.	730402	CH-53A (MCM)	N. Vietnam	Day	Autorotation with soft impact
7.	730702	CH-53D (MCM)	N. Vietnam	Day	Emergency landing with moderate impact
8.	740719	CH-53D	IN LITIGATION		
9.	761104	CH-53D	Okinawa	Day	High speed impact
10.	790617	CH-53D	N. Carolina	Day	Helicopter ditched following loss of engine

Previous studies of CH-53 Navy and Marine helicopter accidents resulting in destruction or substantial damage have shown that accidents on land occurred almost six times more frequently than those on water. Reference Figure A1, SER-13298, "Crashworthy Fuel System Design Criteria".

The reported events that occurred and the general circumstances under which the accident took place are:

NO.	REPORTED ACCIDENT EVENTS OCCURRING BEFORE IMPACT	WIND	VISIBILITY	AIRCRAFT WEIGHT POUNDS
1	Pilots distracted during approach to night landing - at 15' attempted to climb with full power but struck water nose down.	7 knots	One mile in haze	27000
2	Pilots practicing night TACAN approaches - engine failure and explosion - caused helo to become uncontrollable, fell approx. 1200 ft. before impacting water.	9 knots	7 miles 81°F	22700
3	Hovering at 2 ft. with RAMP down over bunker surrounded by flood - tail blades hit bunker - helo. made several flat turns before impacting water.	Gusts to 30 knots	1/2 mile in heavy rain.	
4	Dual engine flameout due to fuel contamination - entered autorotation at 90 knots, 800'. Flared at 100'.	8 knots	Unlimited	
5	Flying at 150', 12-14 knots with MCM Tow. - tail vibrations were followed by loss of tail rotor which almost severed tail pylon - helo. made several flat turns before impacting water.	12 knots	8 miles 65°F	
6	Tail rotor problems caused vibrations during tow operation - hovered at 100' - lost tail rotor - autorotated onto water - used all available collective to cushion landing.			
7	Engine failure during tow operation at 150' aircraft began to descend, rotor RPM at 55%; at 50' leveled aircraft, released tow and applied collective to cushion landing.	Light		30660
8	IN LITIGATION			
9	Picked up passenger on island, during return flight, both engines believed to have flamed only due to fuel starvation, steep descent from 500', flared fell from 100'	9 knots	10 miles 73°F	
10	Took off from ship, engine failed - rotor RPM dropped to 85%, dropped collective, leveled helo. and cushioned landing for controlled ditching with rotor at 80% N_R.	8 knots	7 miles 72°F	35000

The reported helicopter configuration, attitude and velocities at impact with the water are:

NO	HELICOPTER CONFIGURATION	SEA STATE OR WAVES	IMPACT ATTITUDE	IMPACT VELOCITY
1	Probably wheels down -	Calm, 1 - 2 ft. waves	45° Nose down	50-55 knots Fwd. speed
2	Probably wheels down -	4-5 ft. waves 10/minute	Tail low	In autorotation
3	Ramp open - Probably wheels down	Flooded River	Upright	Low speed - making flat turns
4	4 internal aux. fuel tanks in Cabin wheels down - upper ramp door was up - personnel door was open.	1-2 ft. waves	Upright	Flew 100 yds after flare at 40 knots with tail hitting water - settled into water.
5	Wheels up - MCM configuration	Calm	Upright	Right descending spin - violent impact.
6	MCM Configuration. Ramp raised - Boom stowed - DAM in place, tail pylon broken off -	Unknown	Slightly tail low	Autorotation with full collective low speed into water
7	Cockpit windows open - cargo hook well door open - Ramp level, wheels down - some cabin windows missing (Ramp separated on impact).	Sea State 1 3' waves 2 seconds	Level	200-300 fpm. 3-5 knots fwd speed.
8	IN LITIGATION			
9	Gear down	Unknown	Presumed upright	Fell from 100' violent impact.
10	Ramp open, cargo in cabin, gear down	Sea State 2	Level	Zero airspeed cushioned ditching

The reported events immediately following impact with the water are:

NO.	REPORTED EVENTS AFTER IMPACT WITH WATER
1	On impact, pilot in seat went through nose, tail broke off, helicopter rolled over and floated inverted for approximately 20 minutes, then sank in 120' of water. "Water was full of gas".
2	Fire started, burned for 10-15 minutes, aircraft sank rapidly in upright attitude, many pieces of floating debris.
3	Pilot secured engines and applied rotor brake. Crew and passengers abandoned aircraft which sank in 15 ft. of water. Aircraft rolled on right side after rotor blades stopped.
4	Lower nose windows broken - cockpit filled with water - helo rocked back, came to rest - rolled inverted seconds after - internal fuel tanks kept floor 30 inches above water - remained afloat for a considerable time, then sank.
5	After violent initial impact, main rotor blades hit water, began to disintegrate, aircraft rolled inverted (to left) and filled with water. Sank in 2-3 minutes in 63 ft. of water. Tail section severed by tail rotor.
6	After gentle landing, rotor RPM decayed and blades hit water. Aircraft rolled left, pitched nose down. Crew evacuated helo which sank in 1-1 1/2 minutes, tail pylon section broke off. MCM DAM failed allowing big influx of water.
7	After landing on water, helicopter rolled steadily to left. Pilot's windows were open, cockpit and cabin filled with water. Helicopter rolled inverted, crew climbed on it until rescued 10 minutes later. Floated with two ft. of fuselage above water. Sank in 37' water.
8	IN LITIGATION
9	After violent impact, helicopter sank at once. Cabin section found on bottom. Cockpit not found. Water 200-260' deep, strong currents. Debris in water included tail pylon, right landing gear, crew chief's seat.
10	After ditching, floated with rotor at 80%. Secured engines, applied rotor brake, turned 200° counterclockwise. Crew and passengers egressed, aircraft was sitting undamaged in water. Ship struck port side - helicopter sank after collision.

The occupants and their injuries, if any, are tabulated below:

NO	NO. OF OCCUPANTS	UNINJURED	MINOR INJURIES	MAJOR INJURIES	FATALITIES
1	5 Crew	1	1- Crew Chief, thrown from jump seat by impact, bruises, sprained ankle.	2- Pilot, cut leg when thrown thru canopy. Co-pilot, cut leg from control panel.	1- Injuries & cause of death not determined.
2	5 Crew	0	0	1- Co-pilot, major injuries received on impact- Hand released restraint prior to impact.	4- 3 drowned 1 not found All wearing flak vests, not life vests.
3	5 Crew 35 Passengers	4 Crew 35 Passengers.	0	0	1- Crew, Gunner found drowned
4	5 Crew 7 Passengers	12	0	0	0
5	5 Crew 1 Passenger	0	0	6- Pilot-sprained back; Co-pilot-aspiration pneumonia; Crew chief fractured vertebrae-ribs; 1st mech.-fractured vertebrae-ribs; Rad. Op.- possible fractured ribs; Passenger- Facial cuts, broken teeth	0
6	5 Crew	3	2-Crew - cuts, bruises and abrasions from collapse of troop seats in gentle impact.		
7	4 Crew	4			
8	IN LITIGATION				
9	4 Crew				4 missing
10	4 Crew 5 Passengers	4 Crew 5 Passengers			

One item of significance in water accidents is the availability of rotor control at the time of the accident. The following table contains the best estimates of that available in the ten accidents.

NO.	ESTIMATE OF AVAILABLE ROTOR CONTROL
1	Complete control available.
2	Helicopter Uncontrollable
3	Main Rotor Control available, but not directional control.
4	Complete control available.
5	Main Rotor Control available until the blades impacted water - No directional control.
6	Main Rotor Control available until the blades impacted water - No directional control.
7	Little control available as rotor speed dropped to 55% N_R.
8	IN LITIGATION
9	Complete control available
10	Complete control available, rotor RPM dropped to 85% N_R

14.2 Summary of Findings

1) Accidents, as might be expected, occurred at any time and had several different causes. The surveyed accidents included mechanical problems such as loss of directional control, loss of power due to engine problems, fuel contamination, and fuel starvation, all of which resulting in the crew having to make an autorotational descent and subsequent ditching. In other accidents the helicopters were inadvertently flown into the water.

2) The weight of the aircraft involved in the accidents varied considerably; some flights involved crew training and practice missions with no cargo or passengers, while other operations involved full loads of cargo and personnel. Other accidents involved helicopters equipped for Mine Counter Measures (MCM) operations at intermediate gross weights.

3) The majority of the accidents were reported to have occurred in sea state 2 wave conditions (1 to 3 foot waves) with one in calm water, also one in Sea State 3 (3 to 5 foot waves). However, with one exception, recorded wind conditions were below 12 knots. In that accident, gusts to 30 knots were recorded.

4) In the accidents involving autorotation and ditching, a wide range of impact velocities was recorded. In some of the accidents, both the vertical and horizontal velocities were low and water entry was gentle. In one accident, the helicopter was flying at 40 knots while the tail skag was hitting the water, while in other impacts the forward speed was low but the vertical velocity caused a violent impact. Other accidents occurred in which the helicopter entered the water while rotating about the axis of the main rotor.

5) In the majority of the accidents, the helicopter attitude at impact with the water was essentially upright with little or no roll and from zero to 15° nose up pitch. In one account in which the helicopter was inadvertently flown into the water, the impact attitude was recorded to be 45° nose down.

6) In most of the accidents the landing gear was down, being reported as retracted in only one of the MCM mission accidents. In one-third of the accidents the rear ramp was open. In one accident the upper ramp door and the personnel door were open, while in another, the cockpit windows and cargo hook well door were open and some cabin windows were missing.

7) All of the helicopters involved in the surveyed accidents sank. One broke up on impact and sank at once. One was on fire and sank rapidly. Six others rolled inverted and floated for times ranging from 11½ minutes to 20 minutes. A ninth, which was floating on the water undamaged, was struck and damaged by a ship and then sank.

8) In 9 accidents with 42 crew members, 21 were uninjured, 3 received minor injuries, and 8 received major injuries and 10 fatalities occurred, 4 known drowned, 1 undetermined, and 5 missing. In 4 accidents in which 48 passengers were carried, 47 were uninjured, while the 48th received major injuries in the form of facial cuts and broken teeth.

14.3 Design Guide Lines

As a result of the findings of this study of Navy CH-53 helicopter accidents, the following recommendations are made pertaining to the design criteria for stability and flotation of large transport helicopters.

A helicopter flotation/stability system shall be designed to:

1. Accommodate the full range of aircraft weight and c.g. positions.

2. Accommodate the full range of anticipated aircraft configurations. Closures, such as doors, windows, hatches, etc. that may be opened in flight shall not be considered closed in emergency or accident situations.

3. Keep the aircraft upright in Sea State 3 (3 to 5 foot waves) with winds to 30 knots, and keep the aircraft afloat for a time sufficient for the evacuation of a full complement of crew and passengers in these conditions.